

## Measurement Conditions

DASY system configuration, as far as not given on page 1.

|                              |                                              |                                  |
|------------------------------|----------------------------------------------|----------------------------------|
| DASY Version                 | DASY5                                        | V52.10.3                         |
| Extrapolation                | Advanced Extrapolation                       |                                  |
| Phantom                      | Modular Flat Phantom                         |                                  |
| Distance Dipole Center - TSL | 10 mm                                        | with Spacer                      |
| Zoom Scan Resolution         | dx, dy = 4 mm, dz = 1.4 mm                   | Graded Ratio = 1.4 (Z direction) |
| Frequency                    | 3900 MHz $\pm$ 1 MHz<br>4100 MHz $\pm$ 1 MHz |                                  |

## Head TSL parameters at 3900 MHz

The following parameters and calculations were applied.

|                                         | Temperature         | Permittivity   | Conductivity         |
|-----------------------------------------|---------------------|----------------|----------------------|
| Nominal Head TSL parameters             | 22.0 °C             | 37.5           | 3.32 mho/m           |
| Measured Head TSL parameters            | (22.0 $\pm$ 0.2) °C | 36.6 $\pm$ 6 % | 3.21 mho/m $\pm$ 6 % |
| Head TSL temperature change during test | < 0.5 °C            | ----           | ----                 |

## SAR result with Head TSL at 3900 MHz

|                                                       |                    |                              |
|-------------------------------------------------------|--------------------|------------------------------|
| SAR averaged over 1 cm <sup>3</sup> (1 g) of Head TSL | Condition          |                              |
| SAR measured                                          | 100 mW input power | 6.92 W/kg                    |
| SAR for nominal Head TSL parameters                   | normalized to 1W   | 69.2 W/kg $\pm$ 19.9 % (k=2) |

|                                                         |                    |                              |
|---------------------------------------------------------|--------------------|------------------------------|
| SAR averaged over 10 cm <sup>3</sup> (10 g) of Head TSL | condition          |                              |
| SAR measured                                            | 100 mW input power | 2.42 W/kg                    |
| SAR for nominal Head TSL parameters                     | normalized to 1W   | 24.1 W/kg $\pm$ 19.5 % (k=2) |

## Head TSL parameters at 4100 MHz

The following parameters and calculations were applied.

|                                         | Temperature         | Permittivity   | Conductivity         |
|-----------------------------------------|---------------------|----------------|----------------------|
| Nominal Head TSL parameters             | 22.0 °C             | 37.2           | 3.53 mho/m           |
| Measured Head TSL parameters            | (22.0 $\pm$ 0.2) °C | 36.3 $\pm$ 6 % | 3.39 mho/m $\pm$ 6 % |
| Head TSL temperature change during test | < 0.5 °C            | ----           | ----                 |

## SAR result with Head TSL at 4100 MHz

|                                                       |                    |                              |
|-------------------------------------------------------|--------------------|------------------------------|
| SAR averaged over 1 cm <sup>3</sup> (1 g) of Head TSL | Condition          |                              |
| SAR measured                                          | 100 mW input power | 6.79 W/kg                    |
| SAR for nominal Head TSL parameters                   | normalized to 1W   | 67.9 W/kg $\pm$ 19.9 % (k=2) |

|                                                         |                    |                              |
|---------------------------------------------------------|--------------------|------------------------------|
| SAR averaged over 10 cm <sup>3</sup> (10 g) of Head TSL | condition          |                              |
| SAR measured                                            | 100 mW input power | 2.36 W/kg                    |
| SAR for nominal Head TSL parameters                     | normalized to 1W   | 23.5 W/kg $\pm$ 19.5 % (k=2) |

## Appendix (Additional assessments outside the scope of SCS 0108)

### Antenna Parameters with Head TSL at 3900 MHz

|                                      |                                |
|--------------------------------------|--------------------------------|
| Impedance, transformed to feed point | 48.3 $\Omega$ - 4.9 j $\Omega$ |
| Return Loss                          | - 25.6 dB                      |

### Antenna Parameters with Head TSL at 4100 MHz

|                                      |                                |
|--------------------------------------|--------------------------------|
| Impedance, transformed to feed point | 59.0 $\Omega$ - 0.8 j $\Omega$ |
| Return Loss                          | - 21.6 dB                      |

### General Antenna Parameters and Design

|                                  |          |
|----------------------------------|----------|
| Electrical Delay (one direction) | 1.107 ns |
|----------------------------------|----------|

After long term use with 100W radiated power, only a slight warming of the dipole near the feedpoint can be measured.

The dipole is made of standard semirigid coaxial cable. The center conductor of the feeding line is directly connected to the second arm of the dipole. The antenna is therefore short-circuited for DC-signals. On some of the dipoles, small end caps are added to the dipole arms in order to improve matching when loaded according to the position as explained in the "Measurement Conditions" paragraph. The SAR data are not affected by this change. The overall dipole length is still according to the Standard.

No excessive force must be applied to the dipole arms, because they might bend or the soldered connections near the feedpoint may be damaged.

### Additional EUT Data

|                 |       |
|-----------------|-------|
| Manufactured by | SPEAG |
|-----------------|-------|

Test Laboratory: SPEAG, Zurich, Switzerland

## DUT: Dipole 3900 MHz; Type: D3900V2; Serial: D3900V2 - SN:1033

Communication System: UID 0 - CW; Frequency: 3900 MHz, Frequency: 4100 MHz

Medium parameters used:  $f = 3900$  MHz;  $\sigma = 3.21$  S/m;  $\epsilon_r = 36.6$ ;  $\rho = 1000$  kg/m<sup>3</sup>,

Medium parameters used:  $f = 4100$  MHz;  $\sigma = 3.39$  S/m;  $\epsilon_r = 36.3$ ;  $\rho = 1000$  kg/m<sup>3</sup>

Phantom section: Flat Section

Measurement Standard: DASY5 (IEEE/IEC/ANSI C63.19-2011)

### DASY52 Configuration:

- Probe: EX3DV4 - SN3503; ConvF(7.25, 7.25, 7.25) @ 3900 MHz, ConvF(7.05, 7.05, 7.05) @ 4100 MHz; Calibrated: 25.03.2019
- Sensor-Surface: 1.4mm (Mechanical Surface Detection)
- Electronics: DAE4 Sn601; Calibrated: 30.04.2019
- Phantom: Flat Phantom 5.0 (front); Type: QD 000 P50 AA; Serial: 1001
- DASY52 52.10.3(1513); SEMCAD X 14.6.13(7474)

### Dipole Calibration for Head Tissue/Pin=100 mW, d=10mm, f=3900MHz/Zoom Scan, dist=1.4mm (8x8x8)/Cube 0: Measurement grid: dx=4mm, dy=4mm, dz=1.4mm

Reference Value = 71.87 V/m; Power Drift = 0.09 dB

Peak SAR (extrapolated) = 19.1 W/kg

**SAR(1 g) = 6.92 W/kg; SAR(10 g) = 2.42 W/kg**

Smallest distance from peaks to all points 3 dB below = 8 mm

Ratio of SAR at M2 to SAR at M1 = 74.8%

Maximum value of SAR (measured) = 13.4 W/kg

### Dipole Calibration for Head Tissue/Pin=100 mW, d=10mm, f=4100MHz/Zoom Scan, dist=1.4mm (8x8x8)/Cube 0: Measurement grid: dx=4mm, dy=4mm, dz=1.4mm

Reference Value = 70.24 V/m; Power Drift = 0.01 dB

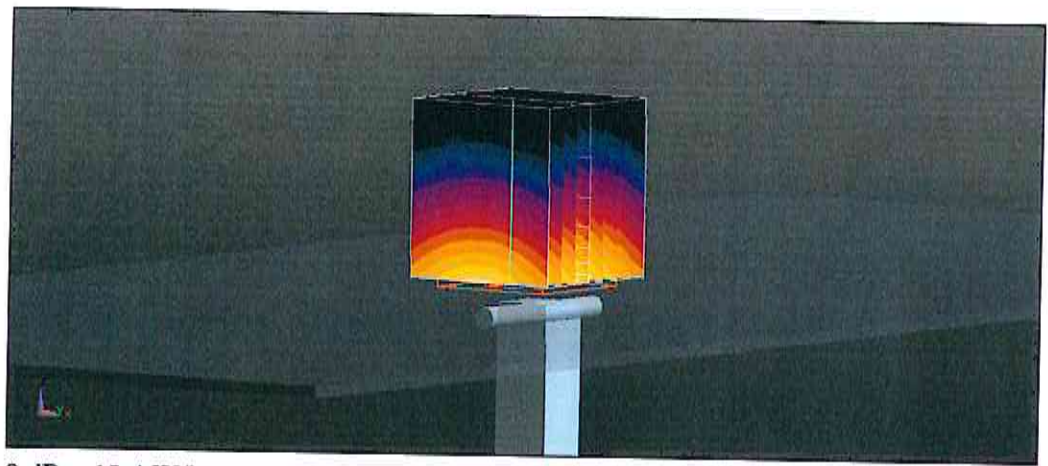
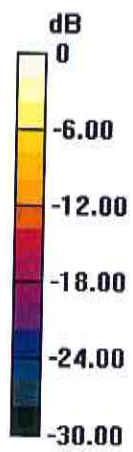
Peak SAR (extrapolated) = 19.4 W/kg

**SAR(1 g) = 6.79 W/kg; SAR(10 g) = 2.36 W/kg**

Smallest distance from peaks to all points 3 dB below = 8 mm

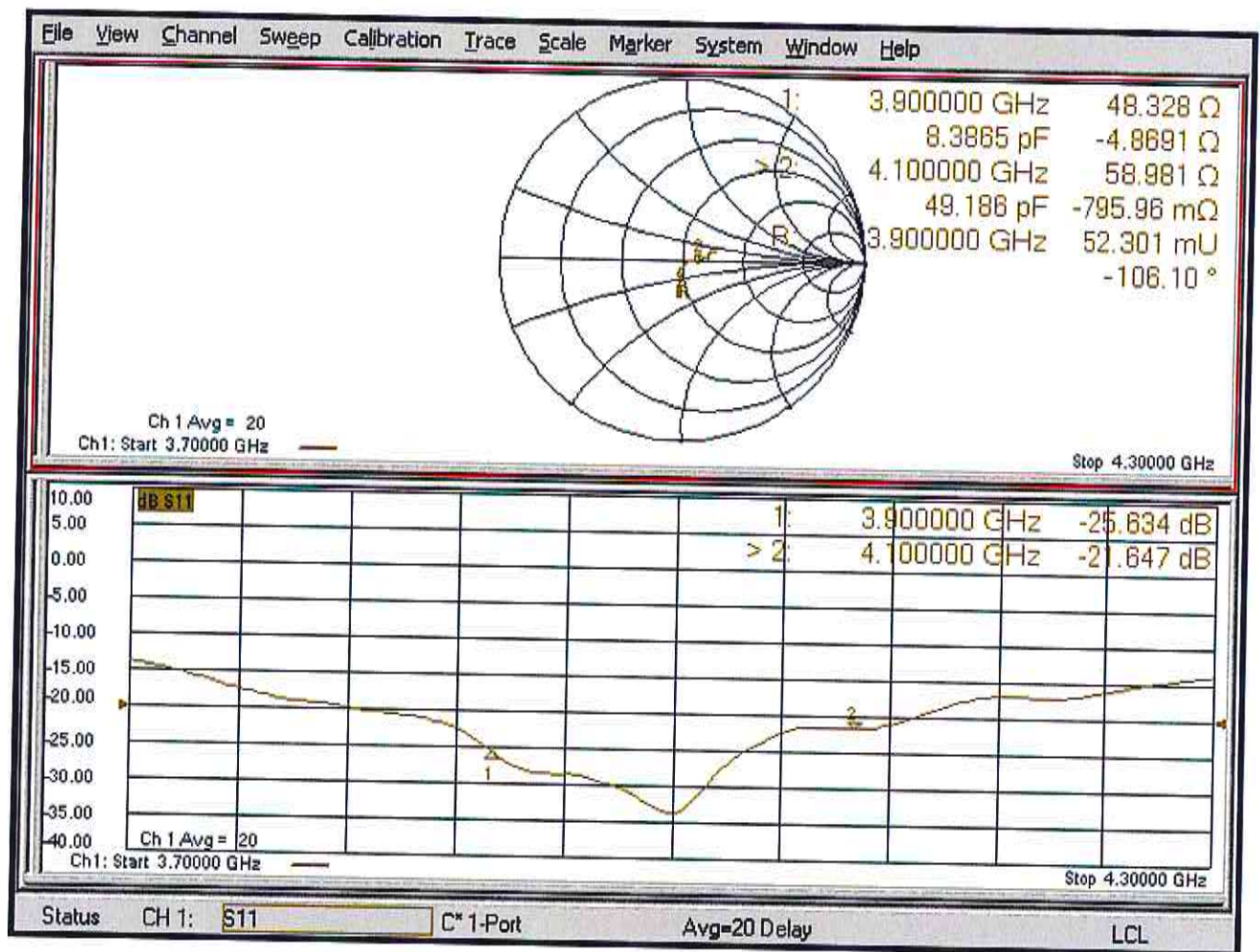
Ratio of SAR at M2 to SAR at M1 = 73.6%

Maximum value of SAR (measured) = 13.4 W/kg



0 dB = 13.4 W/kg = 11.27 dBW/kg

# Impedance Measurement Plot for Head TSL





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Multilateral Agreement for the recognition of calibration certificates

Accreditation No.: **SCS 0108**

Client **SRTC-BJ (Auden)**

Certificate No: **D4200V2-1013\_Nov19**

## CALIBRATION CERTIFICATE

Object **D4200V2 - SN:1013**

Calibration procedure(s) **QA CAL-22.v4  
Calibration Procedure for SAR Validation Sources between 3-6 GHz**

Calibration date: **November 12, 2019**

This calibration certificate documents the traceability to national standards, which realize the physical units of measurements (SI).  
The measurements and the uncertainties with confidence probability are given on the following pages and are part of the certificate.

All calibrations have been conducted in the closed laboratory facility: environment temperature ( $22 \pm 3$ )°C and humidity < 70%.

Calibration Equipment used (M&TE critical for calibration)

| Primary Standards           | ID #               | Cal Date (Certificate No.)      | Scheduled Calibration |
|-----------------------------|--------------------|---------------------------------|-----------------------|
| Power meter NRP             | SN: 104778         | 03-Apr-19 (No. 217-02892/02893) | Apr-20                |
| Power sensor NRP-Z91        | SN: 103244         | 03-Apr-19 (No. 217-02892)       | Apr-20                |
| Power sensor NRP-Z91        | SN: 103245         | 03-Apr-19 (No. 217-02893)       | Apr-20                |
| Reference 20 dB Attenuator  | SN: 5058 (20k)     | 04-Apr-19 (No. 217-02894)       | Apr-20                |
| Type-N mismatch combination | SN: 5047.2 / 06327 | 04-Apr-19 (No. 217-02895)       | Apr-20                |
| Reference Probe EX3DV4      | SN: 3503           | 25-Mar-19 (No. EX3-3503_Mar19)  | Mar-20                |
| DAE4                        | SN: 601            | 30-Apr-19 (No. DAE4-601_Apr19)  | Apr-20                |

| Secondary Standards             | ID #           | Check Date (in house)             | Scheduled Check        |
|---------------------------------|----------------|-----------------------------------|------------------------|
| Power meter E4419B              | SN: GB39512475 | 30-Oct-14 (in house check Feb-19) | In house check: Oct-20 |
| Power sensor HP 8481A           | SN: US37292783 | 07-Oct-15 (in house check Oct-18) | In house check: Oct-20 |
| Power sensor HP 8481A           | SN: MY41092317 | 07-Oct-15 (in house check Oct-18) | In house check: Oct-20 |
| RF generator R&S SMT-06         | SN: 100972     | 15-Jun-15 (in house check Oct-18) | In house check: Oct-20 |
| Network Analyzer Agilent E8358A | SN: US41080477 | 31-Mar-14 (in house check Oct-19) | In house check: Oct-20 |

|                |                |                       |                  |
|----------------|----------------|-----------------------|------------------|
|                | <b>Name</b>    | <b>Function</b>       | <b>Signature</b> |
| Calibrated by: | Jeton Kastrati | Laboratory Technician |                  |
| Approved by:   | Katja Pokovic  | Technical Manager     |                  |

Issued: November 12, 2019

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Multilateral Agreement for the recognition of calibration certificates

Accreditation No.: **SCS 0108**

**Glossary:**

|       |                                 |
|-------|---------------------------------|
| TSL   | tissue simulating liquid        |
| ConvF | sensitivity in TSL / NORM x,y,z |
| N/A   | not applicable or not measured  |

**Calibration is Performed According to the Following Standards:**

- IEEE Std 1528-2013, "IEEE Recommended Practice for Determining the Peak Spatial-Averaged Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques", June 2013
- IEC 62209-1, "Measurement procedure for the assessment of Specific Absorption Rate (SAR) from hand-held and body-mounted devices used next to the ear (frequency range of 300 MHz to 6 GHz)", July 2016
- IEC 62209-2, "Procedure to determine the Specific Absorption Rate (SAR) for wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz)", March 2010
- KDB 865664, "SAR Measurement Requirements for 100 MHz to 6 GHz"

**Additional Documentation:**

- DASY4/5 System Handbook

**Methods Applied and Interpretation of Parameters:**

- Measurement Conditions:** Further details are available from the Validation Report at the end of the certificate. All figures stated in the certificate are valid at the frequency indicated.
- Antenna Parameters with TSL:** The dipole is mounted with the spacer to position its feed point exactly below the center marking of the flat phantom section, with the arms oriented parallel to the body axis.
- Feed Point Impedance and Return Loss:** These parameters are measured with the dipole positioned under the liquid filled phantom. The impedance stated is transformed from the measurement at the SMA connector to the feed point. The Return Loss ensures low reflected power. No uncertainty required.
- Electrical Delay:** One-way delay between the SMA connector and the antenna feed point. No uncertainty required.
- SAR measured:** SAR measured at the stated antenna input power.
- SAR normalized:** SAR as measured, normalized to an input power of 1 W at the antenna connector.
- SAR for nominal TSL parameters:** The measured TSL parameters are used to calculate the nominal SAR result.

The reported uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor  $k=2$ , which for a normal distribution corresponds to a coverage probability of approximately 95%.

## Measurement Conditions

DASY system configuration, as far as not given on page 1.

|                              |                            |                                  |
|------------------------------|----------------------------|----------------------------------|
| DASY Version                 | DASY5                      | V52.10.3                         |
| Extrapolation                | Advanced Extrapolation     |                                  |
| Phantom                      | Modular Flat Phantom       |                                  |
| Distance Dipole Center - TSL | 10 mm                      | with Spacer                      |
| Zoom Scan Resolution         | dx, dy = 4 mm, dz = 1.4 mm | Graded Ratio = 1.4 (Z direction) |
| Frequency                    | 4300 MHz $\pm$ 1 MHz       |                                  |

## Head TSL parameters at 4300 MHz

The following parameters and calculations were applied.

|                                         | Temperature         | Permittivity   | Conductivity         |
|-----------------------------------------|---------------------|----------------|----------------------|
| Nominal Head TSL parameters             | 22.0 °C             | 37.0           | 3.73 mho/m           |
| Measured Head TSL parameters            | (22.0 $\pm$ 0.2) °C | 36.1 $\pm$ 6 % | 3.57 mho/m $\pm$ 6 % |
| Head TSL temperature change during test | < 0.5 °C            | ----           | ----                 |

## SAR result with Head TSL at 4300 MHz

| SAR averaged over 1 cm <sup>3</sup> (1 g) of Head TSL | Condition          |                              |
|-------------------------------------------------------|--------------------|------------------------------|
| SAR measured                                          | 100 mW input power | 6.80 W/kg                    |
| SAR for nominal Head TSL parameters                   | normalized to 1W   | 67.9 W/kg $\pm$ 19.9 % (k=2) |

| SAR averaged over 10 cm <sup>3</sup> (10 g) of Head TSL | condition          |                              |
|---------------------------------------------------------|--------------------|------------------------------|
| SAR measured                                            | 100 mW input power | 2.32 W/kg                    |
| SAR for nominal Head TSL parameters                     | normalized to 1W   | 23.1 W/kg $\pm$ 19.5 % (k=2) |

## Appendix (Additional assessments outside the scope of SCS 0108)

### Antenna Parameters with Head TSL at 4300 MHz

|                                      |                                |
|--------------------------------------|--------------------------------|
| Impedance, transformed to feed point | 52.1 $\Omega$ - 1.6 j $\Omega$ |
| Return Loss                          | - 31.7 dB                      |

### General Antenna Parameters and Design

|                                  |          |
|----------------------------------|----------|
| Electrical Delay (one direction) | 1.112 ns |
|----------------------------------|----------|

After long term use with 100W radiated power, only a slight warming of the dipole near the feedpoint can be measured.

The dipole is made of standard semirigid coaxial cable. The center conductor of the feeding line is directly connected to the second arm of the dipole. The antenna is therefore short-circuited for DC-signals. On some of the dipoles, small end caps are added to the dipole arms in order to improve matching when loaded according to the position as explained in the "Measurement Conditions" paragraph. The SAR data are not affected by this change. The overall dipole length is still according to the Standard.

No excessive force must be applied to the dipole arms, because they might bend or the soldered connections near the feedpoint may be damaged.

### Additional EUT Data

|                 |       |
|-----------------|-------|
| Manufactured by | SPEAG |
|-----------------|-------|

Test Laboratory: SPEAG, Zurich, Switzerland

**DUT: Dipole 4200 MHz; Type: D4200V2; Serial: D4200V2 - SN:1013**

Communication System: UID 0 - CW; Frequency: 4200 MHz, Frequency: 4300 MHz

Medium parameters used:  $f = 4300$  MHz;  $\sigma = 3.57$  S/m;  $\epsilon_r = 36.1$ ;  $\rho = 1000$  kg/m<sup>3</sup>

Phantom section: Flat Section

Measurement Standard: DASY5 (IEEE/IEC/ANSI C63.19-2011)

DASY52 Configuration:

- Probe: EX3DV4 - SN3503; ConvF(6.75, 6.75, 6.75) @ 4300 MHz; Calibrated: 25.03.2019
- Sensor-Surface: 1.4mm (Mechanical Surface Detection)
- Electronics: DAE4 Sn601; Calibrated: 30.04.2019
- Phantom: Flat Phantom 5.0 (front); Type: QD 000 P50 AA; Serial: 1001
- DASY52 52.10.3(1513); SEMCAD X 14.6.13(7474)

**Dipole Calibration for Head Tissue/Pin=100 mW, d=10mm, f=4300MHz/Zoom Scan, dist=1.4mm (8x8x8)/Cube 0:** Measurement grid: dx=4mm, dy=4mm, dz=1.4mm

Reference Value = 70.49 V/m; Power Drift = -0.02 dB

Peak SAR (extrapolated) = 19.8 W/kg

**SAR(1 g) = 6.8 W/kg; SAR(10 g) = 2.32 W/kg**

Smallest distance from peaks to all points 3 dB below = 8 mm

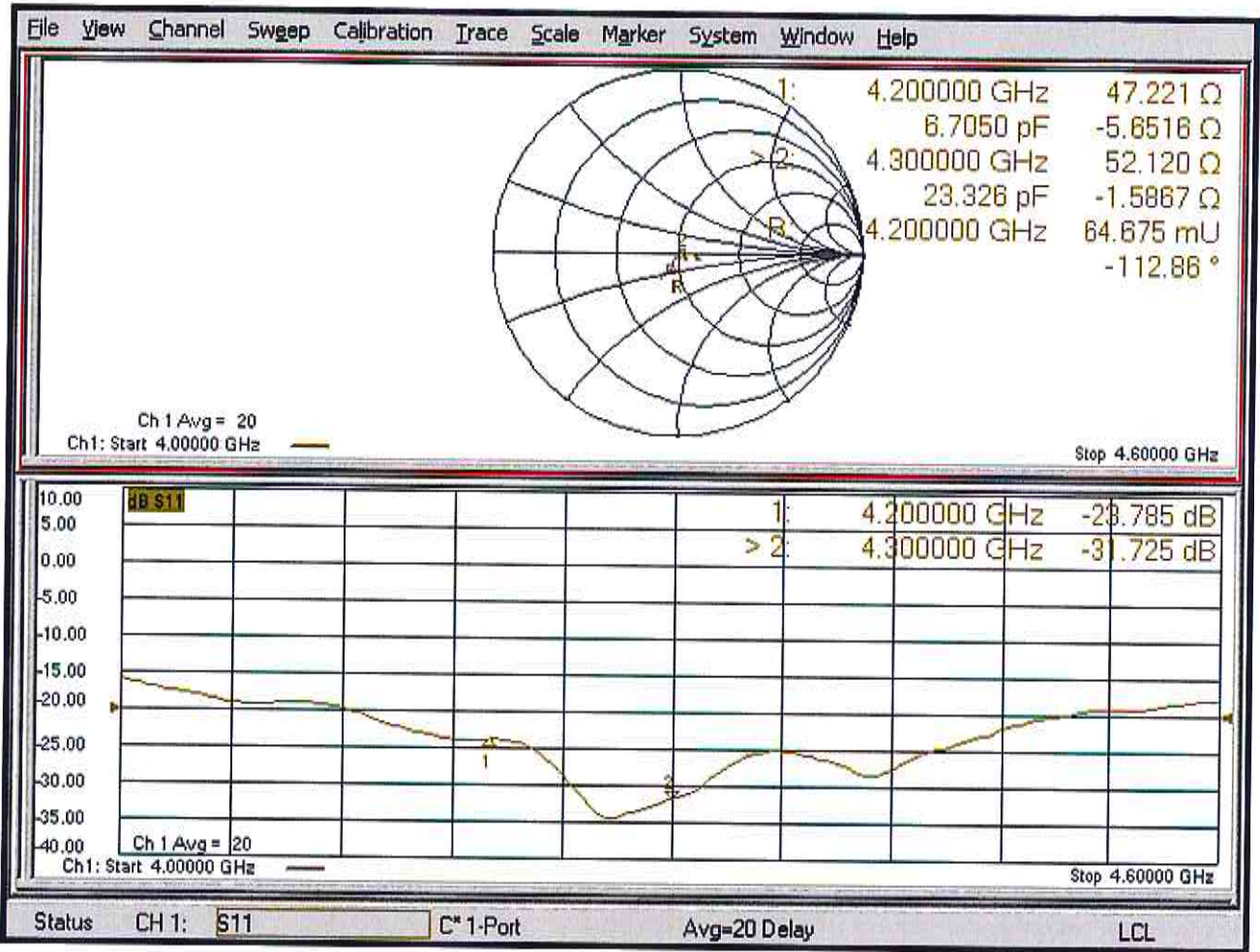
Ratio of SAR at M2 to SAR at M1 = 73.8%

Maximum value of SAR (measured) = 13.6 W/kg



0 dB = 13.6 W/kg = 11.34 dBW/kg

# Impedance Measurement Plot for Head TSL





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Accreditation No.: **SCS 0108**

Client **SRTC-BJ (Auden)**

Certificate No: **D4600V2-1033\_Nov19**

## CALIBRATION CERTIFICATE

Object **D4600V2 - SN:1033**

Calibration procedure(s) **QA CAL-22.v4  
Calibration Procedure for SAR Validation Sources between 3-6 GHz**

Calibration date: **November 12, 2019**

This calibration certificate documents the traceability to national standards, which realize the physical units of measurements (SI).  
The measurements and the uncertainties with confidence probability are given on the following pages and are part of the certificate.

All calibrations have been conducted in the closed laboratory facility: environment temperature ( $22 \pm 3$ )°C and humidity < 70%.

Calibration Equipment used (M&TE critical for calibration)

| Primary Standards               | ID #               | Cal Date (Certificate No.)        | Scheduled Calibration  |
|---------------------------------|--------------------|-----------------------------------|------------------------|
| Power meter NRP                 | SN: 104778         | 03-Apr-19 (No. 217-02892/02893)   | Apr-20                 |
| Power sensor NRP-Z91            | SN: 103244         | 03-Apr-19 (No. 217-02892)         | Apr-20                 |
| Power sensor NRP-Z91            | SN: 103245         | 03-Apr-19 (No. 217-02893)         | Apr-20                 |
| Reference 20 dB Attenuator      | SN: 5058 (20k)     | 04-Apr-19 (No. 217-02894)         | Apr-20                 |
| Type-N mismatch combination     | SN: 5047.2 / 06327 | 04-Apr-19 (No. 217-02895)         | Apr-20                 |
| Reference Probe EX3DV4          | SN: 3503           | 25-Mar-19 (No. EX3-3503_Mar19)    | Mar-20                 |
| DAE4                            | SN: 601            | 30-Apr-19 (No. DAE4-601_Apr19)    | Apr-20                 |
| Secondary Standards             | ID #               | Check Date (in house)             | Scheduled Check        |
| Power meter E4419B              | SN: GB39512475     | 30-Oct-14 (in house check Feb-19) | In house check: Oct-20 |
| Power sensor HP 8481A           | SN: US37292783     | 07-Oct-15 (in house check Oct-18) | In house check: Oct-20 |
| Power sensor HP 8481A           | SN: MY41092317     | 07-Oct-15 (in house check Oct-18) | In house check: Oct-20 |
| RF generator R&S SMT-06         | SN: 100972         | 15-Jun-15 (in house check Oct-18) | In house check: Oct-20 |
| Network Analyzer Agilent E8358A | SN: US41080477     | 31-Mar-14 (in house check Oct-19) | In house check: Oct-20 |

|                |               |                       |           |
|----------------|---------------|-----------------------|-----------|
| Calibrated by: | Name          | Function              | Signature |
|                | Leif Klysner  | Laboratory Technician |           |
| Approved by:   | Name          | Function              | Signature |
|                | Katja Pokovic | Technical Manager     |           |

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Accreditation No.: **SCS 0108**

**Glossary:**

|       |                                 |
|-------|---------------------------------|
| TSL   | tissue simulating liquid        |
| ConvF | sensitivity in TSL / NORM x,y,z |
| N/A   | not applicable or not measured  |

**Calibration is Performed According to the Following Standards:**

- IEEE Std 1528-2013, "IEEE Recommended Practice for Determining the Peak Spatial-Averaged Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques", June 2013
- IEC 62209-1, "Measurement procedure for the assessment of Specific Absorption Rate (SAR) from hand-held and body-mounted devices used next to the ear (frequency range of 300 MHz to 6 GHz)", July 2016
- IEC 62209-2, "Procedure to determine the Specific Absorption Rate (SAR) for wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz)", March 2010
- KDB 865664, "SAR Measurement Requirements for 100 MHz to 6 GHz"

**Additional Documentation:**

- DASY4/5 System Handbook

**Methods Applied and Interpretation of Parameters:**

- Measurement Conditions:** Further details are available from the Validation Report at the end of the certificate. All figures stated in the certificate are valid at the frequency indicated.
- Antenna Parameters with TSL:** The dipole is mounted with the spacer to position its feed point exactly below the center marking of the flat phantom section, with the arms oriented parallel to the body axis.
- Feed Point Impedance and Return Loss:** These parameters are measured with the dipole positioned under the liquid filled phantom. The impedance stated is transformed from the measurement at the SMA connector to the feed point. The Return Loss ensures low reflected power. No uncertainty required.
- Electrical Delay:** One-way delay between the SMA connector and the antenna feed point. No uncertainty required.
- SAR measured:** SAR measured at the stated antenna input power.
- SAR normalized:** SAR as measured, normalized to an input power of 1 W at the antenna connector.
- SAR for nominal TSL parameters:** The measured TSL parameters are used to calculate the nominal SAR result.

The reported uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor  $k=2$ , which for a normal distribution corresponds to a coverage probability of approximately 95%.

## Measurement Conditions

DASY system configuration, as far as not given on page 1.

|                              |                                              |                                  |
|------------------------------|----------------------------------------------|----------------------------------|
| DASY Version                 | DASY5                                        | V52.10.3                         |
| Extrapolation                | Advanced Extrapolation                       |                                  |
| Phantom                      | Modular Flat Phantom                         |                                  |
| Distance Dipole Center - TSL | 10 mm                                        | with Spacer                      |
| Zoom Scan Resolution         | dx, dy = 4 mm, dz = 1.4 mm                   | Graded Ratio = 1.4 (Z direction) |
| Frequency                    | 4500 MHz $\pm$ 1 MHz<br>4700 MHz $\pm$ 1 MHz |                                  |

## Head TSL parameters at 4500 MHz

The following parameters and calculations were applied.

|                                         | Temperature         | Permittivity   | Conductivity         |
|-----------------------------------------|---------------------|----------------|----------------------|
| Nominal Head TSL parameters             | 22.0 °C             | 36.7           | 4.04 mho/m           |
| Measured Head TSL parameters            | (22.0 $\pm$ 0.2) °C | 35.8 $\pm$ 6 % | 3.76 mho/m $\pm$ 6 % |
| Head TSL temperature change during test | < 0.5 °C            | ----           | ----                 |

## SAR result with Head TSL at 4500 MHz

|                                                       |                    |                              |
|-------------------------------------------------------|--------------------|------------------------------|
| SAR averaged over 1 cm <sup>3</sup> (1 g) of Head TSL | Condition          |                              |
| SAR measured                                          | 100 mW input power | 6.93 W/kg                    |
| SAR for nominal Head TSL parameters                   | normalized to 1W   | 69.1 W/kg $\pm$ 19.9 % (k=2) |

|                                                         |                    |                              |
|---------------------------------------------------------|--------------------|------------------------------|
| SAR averaged over 10 cm <sup>3</sup> (10 g) of Head TSL | condition          |                              |
| SAR measured                                            | 100 mW input power | 2.28 W/kg                    |
| SAR for nominal Head TSL parameters                     | normalized to 1W   | 22.6 W/kg $\pm$ 19.5 % (k=2) |

## Head TSL parameters at 4700 MHz

The following parameters and calculations were applied.

|                                         | Temperature         | Permittivity   | Conductivity         |
|-----------------------------------------|---------------------|----------------|----------------------|
| Nominal Head TSL parameters             | 22.0 °C             | 36.6           | 4.14 mho/m           |
| Measured Head TSL parameters            | (22.0 $\pm$ 0.2) °C | 35.6 $\pm$ 6 % | 3.95 mho/m $\pm$ 6 % |
| Head TSL temperature change during test | < 0.5 °C            | ----           | ----                 |

## SAR result with Head TSL at 4700 MHz

|                                                       |                    |                              |
|-------------------------------------------------------|--------------------|------------------------------|
| SAR averaged over 1 cm <sup>3</sup> (1 g) of Head TSL | Condition          |                              |
| SAR measured                                          | 100 mW input power | 6.83 W/kg                    |
| SAR for nominal Head TSL parameters                   | normalized to 1W   | 68.0 W/kg $\pm$ 19.9 % (k=2) |

|                                                         |                    |                              |
|---------------------------------------------------------|--------------------|------------------------------|
| SAR averaged over 10 cm <sup>3</sup> (10 g) of Head TSL | condition          |                              |
| SAR measured                                            | 100 mW input power | 2.22 W/kg                    |
| SAR for nominal Head TSL parameters                     | normalized to 1W   | 22.0 W/kg $\pm$ 19.5 % (k=2) |

## Appendix (Additional assessments outside the scope of SCS 0108)

### Antenna Parameters with Head TSL at 4500 MHz

|                                      |                                |
|--------------------------------------|--------------------------------|
| Impedance, transformed to feed point | 46.4 $\Omega$ - 4.5 j $\Omega$ |
| Return Loss                          | - 24.5 dB                      |

### Antenna Parameters with Head TSL at 4700 MHz

|                                      |                                |
|--------------------------------------|--------------------------------|
| Impedance, transformed to feed point | 55.9 $\Omega$ - 3.2 j $\Omega$ |
| Return Loss                          | - 24.0 dB                      |

### General Antenna Parameters and Design

|                                  |          |
|----------------------------------|----------|
| Electrical Delay (one direction) | 1.108 ns |
|----------------------------------|----------|

After long term use with 100W radiated power, only a slight warming of the dipole near the feedpoint can be measured.

The dipole is made of standard semirigid coaxial cable. The center conductor of the feeding line is directly connected to the second arm of the dipole. The antenna is therefore short-circuited for DC-signals. On some of the dipoles, small end caps are added to the dipole arms in order to improve matching when loaded according to the position as explained in the "Measurement Conditions" paragraph. The SAR data are not affected by this change. The overall dipole length is still according to the Standard.

No excessive force must be applied to the dipole arms, because they might bend or the soldered connections near the feedpoint may be damaged.

### Additional EUT Data

|                 |       |
|-----------------|-------|
| Manufactured by | SPEAG |
|-----------------|-------|

Test Laboratory: SPEAG, Zurich, Switzerland

### DUT: Dipole 4600 MHz; Type: D4600V2; Serial: D4600V2 - SN:1033

Communication System: UID 0 - CW; Frequency: 4500 MHz, Frequency: 4700 MHz

Medium parameters used:  $f = 4500$  MHz;  $\sigma = 3.76$  S/m;  $\epsilon_r = 35.8$ ;  $\rho = 1000$  kg/m<sup>3</sup>,

Medium parameters used:  $f = 4700$  MHz;  $\sigma = 3.95$  S/m;  $\epsilon_r = 35.6$ ;  $\rho = 1000$  kg/m<sup>3</sup>

Phantom section: Flat Section

Measurement Standard: DASY5 (IEEE/IEC/ANSI C63.19-2011)

#### DASY52 Configuration:

- Probe: EX3DV4 - SN3503; ConvF(6.55, 6.55, 6.55) @ 4500 MHz, ConvF(6.25, 6.25, 6.25) @ 4700 MHz; Calibrated: 25.03.2019
- Sensor-Surface: 1.4mm (Mechanical Surface Detection)
- Electronics: DAE4 Sn601; Calibrated: 30.04.2019
- Phantom: Flat Phantom 5.0 (front); Type: QD 000 P50 AA; Serial: 1001
- DASY52 52.10.3(1513); SEMCAD X 14.6.13(7474)

### Dipole Calibration for Head Tissue/Pin=100 mW, d=10mm 4500/Zoom Scan, dist=1.4mm

(8x8x8)/Cube 0: Measurement grid: dx=4mm, dy=4mm, dz=1.4mm

Reference Value = 71.61 V/m; Power Drift = -0.00 dB

Peak SAR (extrapolated) = 20.0 W/kg

**SAR(1 g) = 6.93 W/kg; SAR(10 g) = 2.28 W/kg**

Smallest distance from peaks to all points 3 dB below = 7.9 mm

Ratio of SAR at M2 to SAR at M1 = 73.9%

Maximum value of SAR (measured) = 14.0 W/kg

### Dipole Calibration for Head Tissue/Pin=100 mW, d=10mm 4700/Zoom Scan, dist=1.4mm

(8x8x8)/Cube 0: Measurement grid: dx=4mm, dy=4mm, dz=1.4mm

Reference Value = 70.53 V/m; Power Drift = 0.03 dB

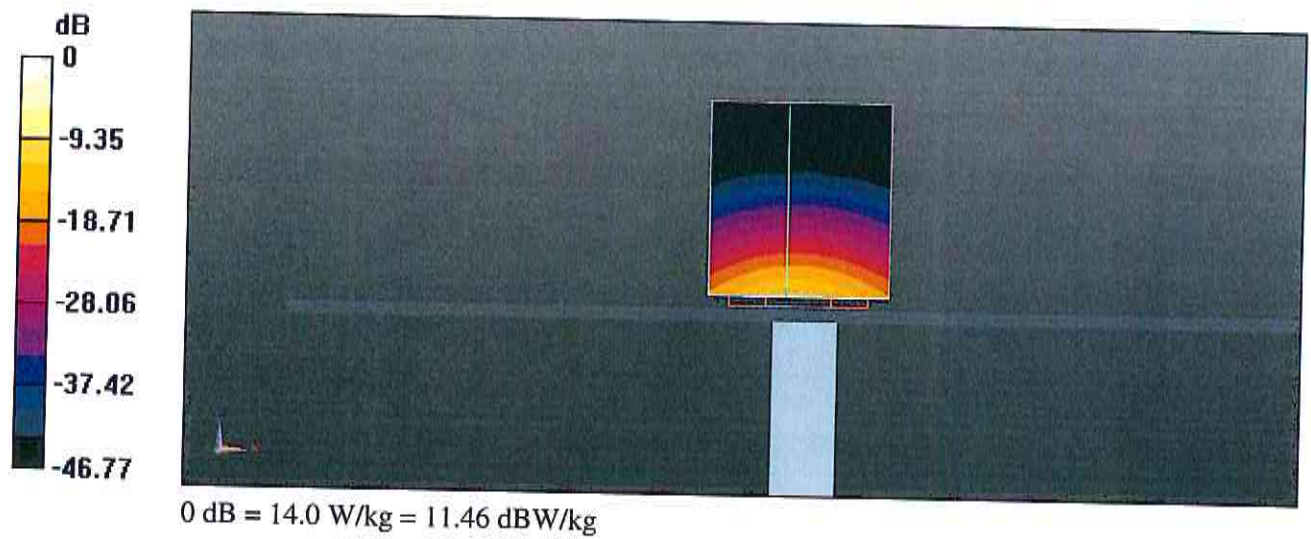
Peak SAR (extrapolated) = 20.7 W/kg

**SAR(1 g) = 6.83 W/kg; SAR(10 g) = 2.22 W/kg**

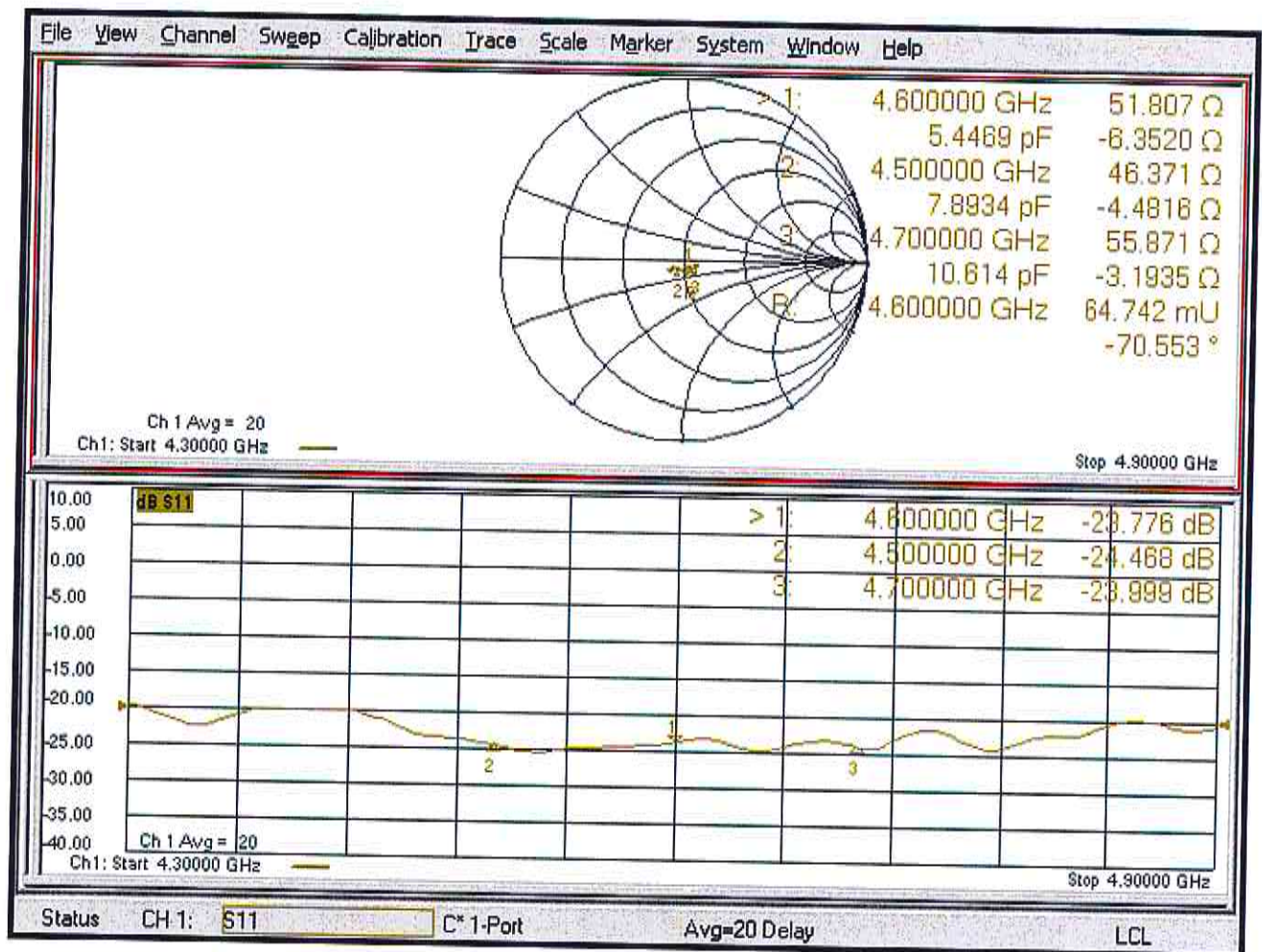
Smallest distance from peaks to all points 3 dB below = 7.9 mm

Ratio of SAR at M2 to SAR at M1 = 72.5%

Maximum value of SAR (measured) = 14.2 W/kg



# Impedance Measurement Plot for Head TSL





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 Multilateral Agreement for the recognition of calibration certificates

Accreditation No.: **SCS 0108**

Client **SRTC-BJ (Auden)**

Certificate No: **D4900V2-1025\_Nov19**

## CALIBRATION CERTIFICATE

Object **D4900V2 - SN:1025**

Calibration procedure(s) **QA CAL-22.v4**  
**Calibration Procedure for SAR Validation Sources between 3-6 GHz**

Calibration date: **November 12, 2019**

This calibration certificate documents the traceability to national standards, which realize the physical units of measurements (SI).  
 The measurements and the uncertainties with confidence probability are given on the following pages and are part of the certificate.

All calibrations have been conducted in the closed laboratory facility: environment temperature  $(22 \pm 3)^{\circ}\text{C}$  and humidity  $< 70\%$ .

Calibration Equipment used (M&TE critical for calibration)

| Primary Standards           | ID #               | Cal Date (Certificate No.)      | Scheduled Calibration |
|-----------------------------|--------------------|---------------------------------|-----------------------|
| Power meter NRP             | SN: 104778         | 03-Apr-19 (No. 217-02892/02893) | Apr-20                |
| Power sensor NRP-Z91        | SN: 103244         | 03-Apr-19 (No. 217-02892)       | Apr-20                |
| Power sensor NRP-Z91        | SN: 103245         | 03-Apr-19 (No. 217-02893)       | Apr-20                |
| Reference 20 dB Attenuator  | SN: 5058 (20k)     | 04-Apr-19 (No. 217-02894)       | Apr-20                |
| Type-N mismatch combination | SN: 5047.2 / 06327 | 04-Apr-19 (No. 217-02895)       | Apr-20                |
| Reference Probe EX3DV4      | SN: 3503           | 25-Mar-19 (No. EX3-3503_Mar19)  | Mar-20                |
| DAE4                        | SN: 601            | 30-Apr-19 (No. DAE4-601_Apr19)  | Apr-20                |

| Secondary Standards             | ID #           | Check Date (in house)             | Scheduled Check        |
|---------------------------------|----------------|-----------------------------------|------------------------|
| Power meter E4419B              | SN: GB39512475 | 30-Oct-14 (in house check Feb-19) | In house check: Oct-20 |
| Power sensor HP 8481A           | SN: US37292783 | 07-Oct-15 (in house check Oct-18) | In house check: Oct-20 |
| Power sensor HP 8481A           | SN: MY41092317 | 07-Oct-15 (in house check Oct-18) | In house check: Oct-20 |
| RF generator R&S SMT-06         | SN: 100972     | 15-Jun-15 (in house check Oct-18) | In house check: Oct-20 |
| Network Analyzer Agilent E8358A | SN: US41080477 | 31-Mar-14 (in house check Oct-19) | In house check: Oct-20 |

|                | Name          | Function              | Signature |
|----------------|---------------|-----------------------|-----------|
| Calibrated by: | Leif Klysner  | Laboratory Technician |           |
| Approved by:   | Katja Pokovic | Technical Manager     |           |

Issued: November 12, 2019

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Multilateral Agreement for the recognition of calibration certificates

Accreditation No.: **SCS 0108**

**Glossary:**

|       |                                 |
|-------|---------------------------------|
| TSL   | tissue simulating liquid        |
| ConvF | sensitivity in TSL / NORM x,y,z |
| N/A   | not applicable or not measured  |

**Calibration is Performed According to the Following Standards:**

- IEEE Std 1528-2013, "IEEE Recommended Practice for Determining the Peak Spatial-Averaged Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques", June 2013
- IEC 62209-1, "Measurement procedure for the assessment of Specific Absorption Rate (SAR) from hand-held and body-mounted devices used next to the ear (frequency range of 300 MHz to 6 GHz)", July 2016
- IEC 62209-2, "Procedure to determine the Specific Absorption Rate (SAR) for wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz)", March 2010
- KDB 865664, "SAR Measurement Requirements for 100 MHz to 6 GHz"

**Additional Documentation:**

- DASY4/5 System Handbook

**Methods Applied and Interpretation of Parameters:**

- Measurement Conditions:** Further details are available from the Validation Report at the end of the certificate. All figures stated in the certificate are valid at the frequency indicated.
- Antenna Parameters with TSL:** The dipole is mounted with the spacer to position its feed point exactly below the center marking of the flat phantom section, with the arms oriented parallel to the body axis.
- Feed Point Impedance and Return Loss:** These parameters are measured with the dipole positioned under the liquid filled phantom. The impedance stated is transformed from the measurement at the SMA connector to the feed point. The Return Loss ensures low reflected power. No uncertainty required.
- Electrical Delay:** One-way delay between the SMA connector and the antenna feed point. No uncertainty required.
- SAR measured:** SAR measured at the stated antenna input power.
- SAR normalized:** SAR as measured, normalized to an input power of 1 W at the antenna connector.
- SAR for nominal TSL parameters:** The measured TSL parameters are used to calculate the nominal SAR result.

The reported uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor  $k=2$ , which for a normal distribution corresponds to a coverage probability of approximately 95%.

## Measurement Conditions

DASY system configuration, as far as not given on page 1.

|                                     |                            |                                  |
|-------------------------------------|----------------------------|----------------------------------|
| <b>DASY Version</b>                 | DASY5                      | V52.10.3                         |
| <b>Extrapolation</b>                | Advanced Extrapolation     |                                  |
| <b>Phantom</b>                      | Modular Flat Phantom       |                                  |
| <b>Distance Dipole Center - TSL</b> | 10 mm                      | with Spacer                      |
| <b>Zoom Scan Resolution</b>         | dx, dy = 4 mm, dz = 1.4 mm | Graded Ratio = 1.4 (Z direction) |
| <b>Frequency</b>                    | 4900 MHz $\pm$ 1 MHz       |                                  |

## Head TSL parameters

The following parameters and calculations were applied.

|                                                | Temperature         | Permittivity   | Conductivity         |
|------------------------------------------------|---------------------|----------------|----------------------|
| <b>Nominal Head TSL parameters</b>             | 22.0 °C             | 36.3           | 4.35 mho/m           |
| <b>Measured Head TSL parameters</b>            | (22.0 $\pm$ 0.2) °C | 35.3 $\pm$ 6 % | 4.15 mho/m $\pm$ 6 % |
| <b>Head TSL temperature change during test</b> | < 0.5 °C            | ----           | ----                 |

## SAR result with Head TSL

|                                                             |                    |                                                |
|-------------------------------------------------------------|--------------------|------------------------------------------------|
| <b>SAR averaged over 1 cm<sup>3</sup> (1 g) of Head TSL</b> | Condition          |                                                |
| SAR measured                                                | 100 mW input power | 7.07 W/kg                                      |
| SAR for nominal Head TSL parameters                         | normalized to 1W   | <b>70.3 W/kg <math>\pm</math> 19.9 % (k=2)</b> |

|                                                               |                    |                                                |
|---------------------------------------------------------------|--------------------|------------------------------------------------|
| <b>SAR averaged over 10 cm<sup>3</sup> (10 g) of Head TSL</b> | condition          |                                                |
| SAR measured                                                  | 100 mW input power | 2.23 W/kg                                      |
| SAR for nominal Head TSL parameters                           | normalized to 1W   | <b>22.1 W/kg <math>\pm</math> 19.5 % (k=2)</b> |

## Appendix (Additional assessments outside the scope of SCS 0108)

### Antenna Parameters with Head TSL

|                                      |                                |
|--------------------------------------|--------------------------------|
| Impedance, transformed to feed point | 50.6 $\Omega$ - 5.2 j $\Omega$ |
| Return Loss                          | - 25.7 dB                      |

### General Antenna Parameters and Design

|                                  |          |
|----------------------------------|----------|
| Electrical Delay (one direction) | 1.091 ns |
|----------------------------------|----------|

After long term use with 100W radiated power, only a slight warming of the dipole near the feedpoint can be measured.

The dipole is made of standard semirigid coaxial cable. The center conductor of the feeding line is directly connected to the second arm of the dipole. The antenna is therefore short-circuited for DC-signals. On some of the dipoles, small end caps are added to the dipole arms in order to improve matching when loaded according to the position as explained in the "Measurement Conditions" paragraph. The SAR data are not affected by this change. The overall dipole length is still according to the Standard.

No excessive force must be applied to the dipole arms, because they might bend or the soldered connections near the feedpoint may be damaged.

### Additional EUT Data

|                 |       |
|-----------------|-------|
| Manufactured by | SPEAG |
|-----------------|-------|

## DASY5 Validation Report for Head TSL

Date: 12.11.2019

Test Laboratory: SPEAG, Zurich, Switzerland

**DUT: Dipole 4900 MHz; Type: D4900V2; Serial: D4900V2 - SN:1025**

Communication System: UID 0 - CW; Frequency: 4900 MHz

Medium parameters used:  $f = 4900$  MHz;  $\sigma = 4.15$  S/m;  $\epsilon_r = 35.3$ ;  $\rho = 1000$  kg/m<sup>3</sup>

Phantom section: Flat Section

Measurement Standard: DASY5 (IEEE/IEC/ANSI C63.19-2011)

DASY52 Configuration:

- Probe: EX3DV4 - SN3503; ConvF(6.05, 6.05, 6.05) @ 4900 MHz; Calibrated: 25.03.2019
- Sensor-Surface: 1.4mm (Mechanical Surface Detection)
- Electronics: DAE4 Sn601; Calibrated: 30.04.2019
- Phantom: Flat Phantom 5.0 (front); Type: QD 000 P50 AA; Serial: 1001
- DASY52 52.10.3(1513); SEMCAD X 14.6.13(7474)

### **Dipole Calibration for Head Tissue/Pin=100 mW, d=10mm 4900/Zoom Scan, dist=1.4mm**

**(8x8x8)/Cube 0:** Measurement grid: dx=4mm, dy=4mm, dz=1.4mm

Reference Value = 71.76 V/m; Power Drift = 0.03 dB

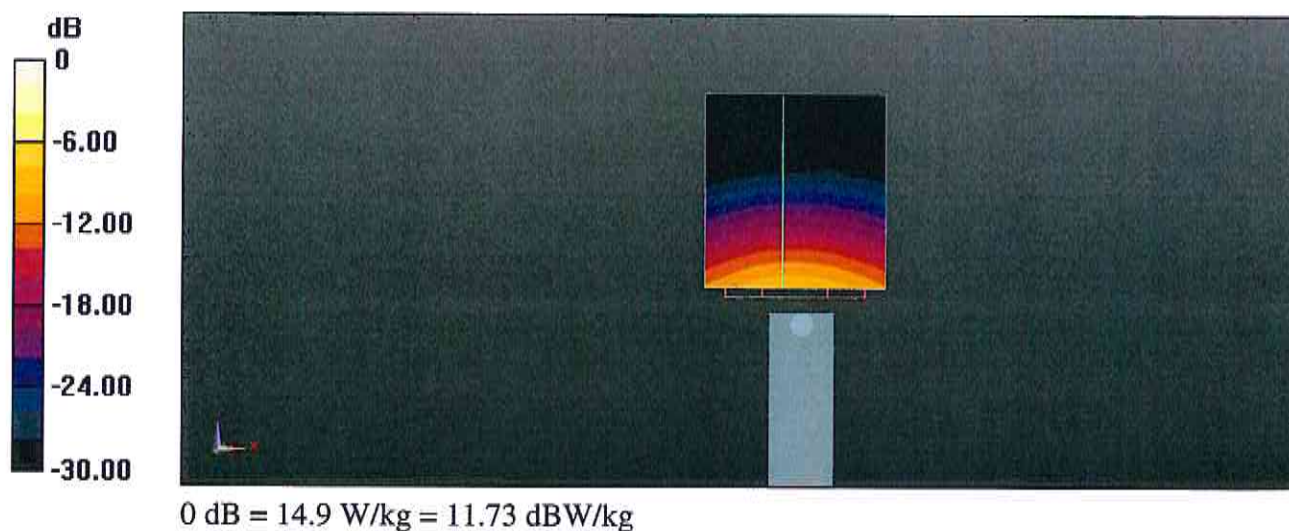
Peak SAR (extrapolated) = 21.6 W/kg

**SAR(1 g) = 7.07 W/kg; SAR(10 g) = 2.23 W/kg**

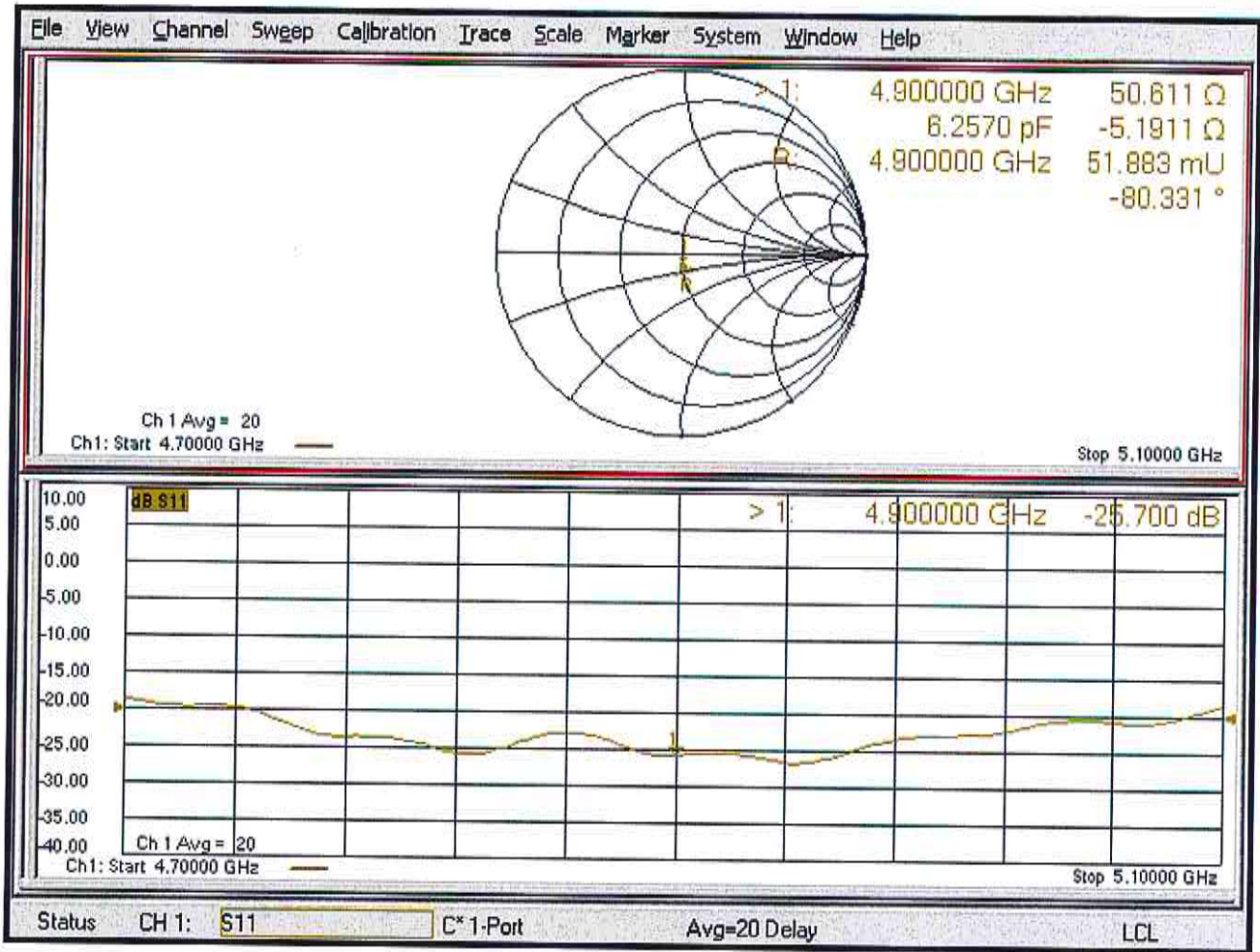
Smallest distance from peaks to all points 3 dB below = 7.6 mm

Ratio of SAR at M2 to SAR at M1 = 72.5%

Maximum value of SAR (measured) = 14.9 W/kg



Impedance Measurement Plot for Head TSL





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Client

**SRTC**

Certificate No: **Z20-60398**

## CALIBRATION CERTIFICATE

Object

D5GHzV2 - SN: 1079

Calibration Procedure(s)

FF-Z11-003-01

Calibration Procedures for dipole validation kits

Calibration date:

October 10, 2020

This calibration Certificate documents the traceability to national standards, which realize the physical units of measurements(SI). The measurements and the uncertainties with confidence probability are given on the following pages and are part of the certificate.

All calibrations have been conducted in the closed laboratory facility: environment temperature(22±3)°C and humidity<70%.

Calibration Equipment used (M&TE critical for calibration)

| Primary Standards       | ID #       | Cal Date(Calibrated by, Certificate No.) | Scheduled Calibration |
|-------------------------|------------|------------------------------------------|-----------------------|
| Power Meter NRP2        | 106276     | 12-May-20 (CTTL, No.J20X02965)           | May-21                |
| Power sensor NRP6A      | 101369     | 12-May-20 (CTTL, No.J20X02965)           | May-21                |
| ReferenceProbe EX3DV4   | SN 3617    | 30-Jan-20(SPEAG,No.EX3-3617_Jan20)       | Jan-21                |
| DAE4                    | SN 771     | 10-Feb-20(CTTL-SPEAG,No.Z20-60017)       | Feb-21                |
| Secondary Standards     | ID #       | Cal Date(Calibrated by, Certificate No.) | Scheduled Calibration |
| Signal Generator E4438C | MY49071430 | 25-Feb-20 (CTTL, No.J20X00516)           | Feb-21                |
| NetworkAnalyzerE5071C   | MY46107873 | 10-Feb-20 (CTTL, No.J20X00515)           | Feb-21                |

|                | Name        | Function           | Signature |
|----------------|-------------|--------------------|-----------|
| Calibrated by: | Zhao Jing   | SAR Test Engineer  |           |
| Reviewed by:   | Lin Hao     | SAR Test Engineer  |           |
| Approved by:   | Qi Dianyuan | SAR Project Leader |           |

Issued: October 22, 2020

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### Glossary:

|       |                                            |
|-------|--------------------------------------------|
| TSL   | tissue simulating liquid                   |
| ConvF | sensitivity in TSL / NORM <sub>x,y,z</sub> |
| N/A   | not applicable or not measured             |

### Calibration is Performed According to the Following Standards:

- IEEE Std 1528-2013, "IEEE Recommended Practice for Determining the Peak Spatial-Averaged Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques", June 2013
- IEC 62209-1, "Measurement procedure for assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices- Part 1: Device used next to the ear (Frequency range of 300MHz to 6GHz)", July 2016
- IEC 62209-2, "Procedure to measure the Specific Absorption Rate (SAR) For wireless communication devices used in close proximity to the human body (frequency range of 30MHz to 6GHz)", March 2010
- KDB865664, SAR Measurement Requirements for 100 MHz to 6 GHz

### Additional Documentation:

- DASY4/5 System Handbook

### Methods Applied and Interpretation of Parameters:

- Measurement Conditions:** Further details are available from the Validation Report at the end of the certificate. All figures stated in the certificate are valid at the frequency indicated.
- Antenna Parameters with TSL:** The dipole is mounted with the spacer to position its feed point exactly below the center marking of the flat phantom section, with the arms oriented parallel to the body axis.
- Feed Point Impedance and Return Loss:** These parameters are measured with the dipole positioned under the liquid filled phantom. The impedance stated is transformed from the measurement at the SMA connector to the feed point. The Return Loss ensures low reflected power. No uncertainty required.
- Electrical Delay:** One-way delay between the SMA connector and the antenna feed point. No uncertainty required.
- SAR measured:** SAR measured at the stated antenna input power.
- SAR normalized:** SAR as measured, normalized to an input power of 1 W at the antenna connector.
- SAR for nominal TSL parameters:** The measured TSL parameters are used to calculate the nominal SAR result.

The reported uncertainty of measurement is stated as the standard uncertainty of Measurement multiplied by the coverage factor  $k=2$ , which for a normal distribution Corresponds to a coverage probability of approximately 95%.



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## Measurement Conditions

DASY system configuration, as far as not given on page 1.

|                              |                                                                                                                      |                                  |
|------------------------------|----------------------------------------------------------------------------------------------------------------------|----------------------------------|
| DASY Version                 | DASY52                                                                                                               | V52.10.4                         |
| Extrapolation                | Advanced Extrapolation                                                                                               |                                  |
| Phantom                      | Triple Flat Phantom 5.1C                                                                                             |                                  |
| Distance Dipole Center - TSL | 10 mm                                                                                                                | with Spacer                      |
| Zoom Scan Resolution         | dx, dy = 4 mm, dz = 1.4 mm                                                                                           | Graded Ratio = 1.4 (Z direction) |
| Frequency                    | 5200 MHz $\pm$ 1 MHz<br>5300 MHz $\pm$ 1 MHz<br>5500 MHz $\pm$ 1 MHz<br>5600 MHz $\pm$ 1 MHz<br>5800 MHz $\pm$ 1 MHz |                                  |

## Head TSL parameters at 5200 MHz

The following parameters and calculations were applied.

|                                         | Temperature         | Permittivity   | Conductivity         |
|-----------------------------------------|---------------------|----------------|----------------------|
| Nominal Head TSL parameters             | 22.0 °C             | 36.0           | 4.66 mho/m           |
| Measured Head TSL parameters            | (22.0 $\pm$ 0.2) °C | 36.0 $\pm$ 6 % | 4.65 mho/m $\pm$ 6 % |
| Head TSL temperature change during test | <1.0 °C             | ----           | ----                 |

## SAR result with Head TSL at 5200 MHz

|                                                         |                    |                              |
|---------------------------------------------------------|--------------------|------------------------------|
| SAR averaged over 1 cm <sup>3</sup> (1 g) of Head TSL   | Condition          |                              |
| SAR measured                                            | 100 mW input power | 7.59 W/kg                    |
| SAR for nominal Head TSL parameters                     | normalized to 1W   | 75.9 W/kg $\pm$ 24.4 % (k=2) |
| SAR averaged over 10 cm <sup>3</sup> (10 g) of Head TSL | Condition          |                              |
| SAR measured                                            | 100 mW input power | 2.14 W/kg                    |
| SAR for nominal Head TSL parameters                     | normalized to 1W   | 21.4 W/kg $\pm$ 24.2 % (k=2) |



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### Head TSL parameters at 5300 MHz

The following parameters and calculations were applied.

|                                         | Temperature     | Permittivity | Conductivity     |
|-----------------------------------------|-----------------|--------------|------------------|
| Nominal Head TSL parameters             | 22.0 °C         | 35.9         | 4.76 mho/m       |
| Measured Head TSL parameters            | (22.0 ± 0.2) °C | 35.8 ± 6 %   | 4.76 mho/m ± 6 % |
| Head TSL temperature change during test | <1.0 °C         | ---          | ---              |

### SAR result with Head TSL at 5300 MHz

|                                                         |                    |                          |
|---------------------------------------------------------|--------------------|--------------------------|
| SAR averaged over 1 cm <sup>3</sup> (1 g) of Head TSL   | Condition          |                          |
| SAR measured                                            | 100 mW input power | 7.81 W/kg                |
| SAR for nominal Head TSL parameters                     | normalized to 1W   | 78.0 W/kg ± 24.4 % (k=2) |
| SAR averaged over 10 cm <sup>3</sup> (10 g) of Head TSL | Condition          |                          |
| SAR measured                                            | 100 mW input power | 2.20 W/kg                |
| SAR for nominal Head TSL parameters                     | normalized to 1W   | 22.0 W/kg ± 24.2 % (k=2) |

### Head TSL parameters at 5500 MHz

The following parameters and calculations were applied.

|                                         | Temperature     | Permittivity | Conductivity     |
|-----------------------------------------|-----------------|--------------|------------------|
| Nominal Head TSL parameters             | 22.0 °C         | 35.6         | 4.96 mho/m       |
| Measured Head TSL parameters            | (22.0 ± 0.2) °C | 35.4 ± 6 %   | 4.97 mho/m ± 6 % |
| Head TSL temperature change during test | <1.0 °C         | ---          | ---              |

### SAR result with Head TSL at 5500 MHz

|                                                         |                    |                          |
|---------------------------------------------------------|--------------------|--------------------------|
| SAR averaged over 1 cm <sup>3</sup> (1 g) of Head TSL   | Condition          |                          |
| SAR measured                                            | 100 mW input power | 8.24 W/kg                |
| SAR for nominal Head TSL parameters                     | normalized to 1W   | 82.3 W/kg ± 24.4 % (k=2) |
| SAR averaged over 10 cm <sup>3</sup> (10 g) of Head TSL | Condition          |                          |
| SAR measured                                            | 100 mW input power | 2.31 W/kg                |
| SAR for nominal Head TSL parameters                     | normalized to 1W   | 23.1 W/kg ± 24.2 % (k=2) |



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### Head TSL parameters at 5600 MHz

The following parameters and calculations were applied.

|                                         | Temperature     | Permittivity | Conductivity     |
|-----------------------------------------|-----------------|--------------|------------------|
| Nominal Head TSL parameters             | 22.0 °C         | 35.5         | 5.07 mho/m       |
| Measured Head TSL parameters            | (22.0 ± 0.2) °C | 35.2 ± 6 %   | 5.08 mho/m ± 6 % |
| Head TSL temperature change during test | <1.0 °C         | ----         | ----             |

### SAR result with Head TSL at 5600 MHz

|                                                         |                    |                          |
|---------------------------------------------------------|--------------------|--------------------------|
| SAR averaged over 1 cm <sup>3</sup> (1 g) of Head TSL   | Condition          |                          |
| SAR measured                                            | 100 mW input power | 8.01 W/kg                |
| SAR for nominal Head TSL parameters                     | normalized to 1W   | 80.0 W/kg ± 24.4 % (k=2) |
| SAR averaged over 10 cm <sup>3</sup> (10 g) of Head TSL | Condition          |                          |
| SAR measured                                            | 100 mW input power | 2.26 W/kg                |
| SAR for nominal Head TSL parameters                     | normalized to 1W   | 22.6 W/kg ± 24.2 % (k=2) |

### Head TSL parameters at 5800 MHz

The following parameters and calculations were applied.

|                                         | Temperature     | Permittivity | Conductivity     |
|-----------------------------------------|-----------------|--------------|------------------|
| Nominal Head TSL parameters             | 22.0 °C         | 35.3         | 5.27 mho/m       |
| Measured Head TSL parameters            | (22.0 ± 0.2) °C | 35.0 ± 6 %   | 5.28 mho/m ± 6 % |
| Head TSL temperature change during test | <1.0 °C         | ----         | ----             |

### SAR result with Head TSL at 5800 MHz

|                                                         |                    |                          |
|---------------------------------------------------------|--------------------|--------------------------|
| SAR averaged over 1 cm <sup>3</sup> (1 g) of Head TSL   | Condition          |                          |
| SAR measured                                            | 100 mW input power | 7.86 W/kg                |
| SAR for nominal Head TSL parameters                     | normalized to 1W   | 78.5 W/kg ± 24.4 % (k=2) |
| SAR averaged over 10 cm <sup>3</sup> (10 g) of Head TSL | Condition          |                          |
| SAR measured                                            | 100 mW input power | 2.20 W/kg                |
| SAR for nominal Head TSL parameters                     | normalized to 1W   | 21.9 W/kg ± 24.2 % (k=2) |



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## Appendix (Additional assessments outside the scope of CNAS L0570)

### Antenna Parameters with Head TSL at 5200 MHz

|                                      |                                |
|--------------------------------------|--------------------------------|
| Impedance, transformed to feed point | 50.2 $\Omega$ - 10.0j $\Omega$ |
| Return Loss                          | - 20.0dB                       |

### Antenna Parameters with Head TSL at 5300 MHz

|                                      |                                |
|--------------------------------------|--------------------------------|
| Impedance, transformed to feed point | 47.2 $\Omega$ - 7.33j $\Omega$ |
| Return Loss                          | - 21.9dB                       |

### Antenna Parameters with Head TSL at 5500 MHz

|                                      |                                |
|--------------------------------------|--------------------------------|
| Impedance, transformed to feed point | 52.0 $\Omega$ - 7.96j $\Omega$ |
| Return Loss                          | - 21.9dB                       |

### Antenna Parameters with Head TSL at 5600 MHz

|                                      |                                |
|--------------------------------------|--------------------------------|
| Impedance, transformed to feed point | 55.7 $\Omega$ - 3.78j $\Omega$ |
| Return Loss                          | - 23.8dB                       |

### Antenna Parameters with Head TSL at 5800 MHz

|                                      |                                |
|--------------------------------------|--------------------------------|
| Impedance, transformed to feed point | 53.7 $\Omega$ - 5.87j $\Omega$ |
| Return Loss                          | - 23.5dB                       |

### General Antenna Parameters and Design

|                                  |          |
|----------------------------------|----------|
| Electrical Delay (one direction) | 1.069 ns |
|----------------------------------|----------|

After long term use with 100W radiated power, only a slight warming of the dipole near the feedpoint can be measured.

The dipole is made of standard semirigid coaxial cable. The center conductor of the feeding line is directly connected to the second arm of the dipole. The antenna is therefore short-circuited for DC-signals. On some of the dipoles, small end caps are added to the dipole arms in order to improve matching when loaded according to the position as explained in the "Measurement Conditions" paragraph. The SAR data are not affected by this change. The overall dipole length is still according to the Standard.

No excessive force must be applied to the dipole arms, because they might bend or the soldered connections near the feedpoint may be damaged.



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### Additional EUT Data

|                 |       |
|-----------------|-------|
| Manufactured by | SPEAG |
|-----------------|-------|



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## **DASY5 Validation Report for Head TSL**

Date: 10.10.2020

Test Laboratory: CTTL, Beijing, China

**DUT: Dipole 5GHz; Type: D5GHzV2; Serial: D5GHzV2 - SN: 1079**

Communication System: CW; Frequency: 5200 MHz, Frequency: 5300 MHz, Frequency: 5500 MHz, Frequency: 5600 MHz, Frequency: 5800 MHz,  
Medium parameters used:  $f = 5200$  MHz;  $\sigma = 4.65$  S/m;  $\epsilon_r = 35.95$ ;  $\rho = 1000$  kg/m<sup>3</sup>,  
Medium parameters used:  $f = 5300$  MHz;  $\sigma = 4.759$  S/m;  $\epsilon_r = 35.75$ ;  $\rho = 1000$  kg/m<sup>3</sup>,  
Medium parameters used:  $f = 5500$  MHz;  $\sigma = 4.969$  S/m;  $\epsilon_r = 35.39$ ;  $\rho = 1000$  kg/m<sup>3</sup>,  
Medium parameters used:  $f = 5600$  MHz;  $\sigma = 5.081$  S/m;  $\epsilon_r = 35.24$ ;  $\rho = 1000$  kg/m<sup>3</sup>,  
Medium parameters used:  $f = 5800$  MHz;  $\sigma = 5.279$  S/m;  $\epsilon_r = 34.97$ ;  $\rho = 1000$  kg/m<sup>3</sup>,

Phantom section: Center Section

**DASY5 Configuration:**

- Probe: EX3DV4 - SN3617; ConvF(5.49, 5.49, 5.49) @ 5200 MHz; ConvF(5.29, 5.29, 5.29) @ 5300 MHz; ConvF(5.14, 5.14, 5.14) @ 5500 MHz; ConvF(4.99, 4.99, 4.99) @ 5600 MHz; ConvF(5, 5, 5) @ 5800 MHz; Calibrated: 2020-01-30
- Sensor-Surface: 1.4mm (Mechanical Surface Detection)
- Electronics: DAE4 Sn771; Calibrated: 2020-02-10
- Phantom: MFP\_V5.1C (20deg probe tilt); Type: QD 000 P51 Cx; Serial: 1062
- Measurement SW: DASY52, Version 52.10 (4); SEMCAD X Version 14.6.14 (7483)

**Dipole Calibration /Pin=100mW, d=10mm, f=5200 MHz/Zoom Scan, dist=1.4mm (8x8x7)/Cube 0:** Measurement grid: dx=4mm, dy=4mm, dz=1.4mm  
Reference Value = 69.85 V/m; Power Drift = 0.07 dB  
Peak SAR (extrapolated) = 30.9 W/kg  
**SAR(1 g) = 7.59 W/kg; SAR(10 g) = 2.14 W/kg**  
Smallest distance from peaks to all points 3 dB below = 7.2 mm  
Ratio of SAR at M2 to SAR at M1 = 64.9%  
Maximum value of SAR (measured) = 18.7 W/kg

**Dipole Calibration /Pin=100mW, d=10mm, f=5300 MHz/Zoom Scan, dist=1.4mm (8x8x7)/Cube 0:** Measurement grid: dx=4mm, dy=4mm, dz=1.4mm  
Reference Value = 68.07 V/m; Power Drift = -0.04 dB  
Peak SAR (extrapolated) = 32.5 W/kg  
**SAR(1 g) = 7.81 W/kg; SAR(10 g) = 2.2 W/kg**  
Smallest distance from peaks to all points 3 dB below = 7.2 mm  
Ratio of SAR at M2 to SAR at M1 = 64.2%  
Maximum value of SAR (measured) = 18.8 W/kg



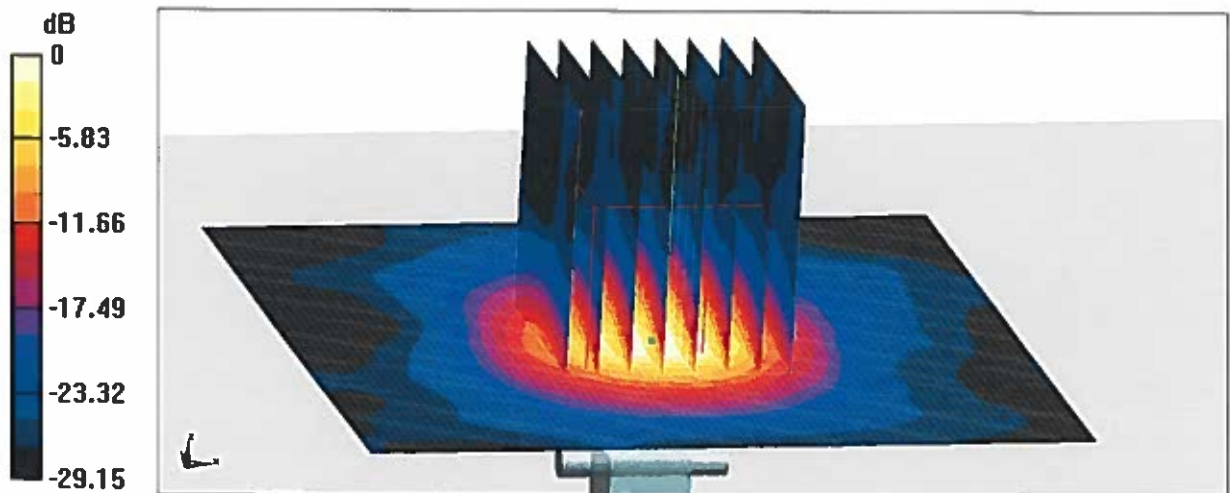
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**Dipole Calibration /Pin=100mW, d=10mm, f=5500 MHz/Zoom Scan,**  
**dist=1.4mm (8x8x7)/Cube 0:** Measurement grid: dx=4mm, dy=4mm, dz=1.4mm  
Reference Value = 69.06 V/m; Power Drift = -0.04 dB  
Peak SAR (extrapolated) = 36.1 W/kg  
**SAR(1 g) = 8.24 W/kg; SAR(10 g) = 2.31 W/kg**  
Smallest distance from peaks to all points 3 dB below = 7.2 mm  
Ratio of SAR at M2 to SAR at M1 = 62.5%  
Maximum value of SAR (measured) = 19.9 W/kg

**Dipole Calibration /Pin=100mW, d=10mm, f=5600 MHz/Zoom Scan,**  
**dist=1.4mm (8x8x7)/Cube 0:** Measurement grid: dx=4mm, dy=4mm, dz=1.4mm  
Reference Value = 67.87 V/m; Power Drift = -0.05 dB  
Peak SAR (extrapolated) = 36.0 W/kg  
**SAR(1 g) = 8.01 W/kg; SAR(10 g) = 2.26 W/kg**  
Smallest distance from peaks to all points 3 dB below = 7.2 mm  
Ratio of SAR at M2 to SAR at M1 = 61.7%  
Maximum value of SAR (measured) = 19.9 W/kg

**Dipole Calibration /Pin=100mW, d=10mm, f=5800 MHz/Zoom Scan,**  
**dist=1.4mm (8x8x7)/Cube 0:** Measurement grid: dx=4mm, dy=4mm, dz=1.4mm  
Reference Value = 68.36 V/m; Power Drift = -0.08 dB  
Peak SAR (extrapolated) = 37.0 W/kg  
**SAR(1 g) = 7.86 W/kg; SAR(10 g) = 2.2 W/kg**  
Smallest distance from peaks to all points 3 dB below = 7.2 mm  
Ratio of SAR at M2 to SAR at M1 = 60.2%  
Maximum value of SAR (measured) = 19.3 W/kg

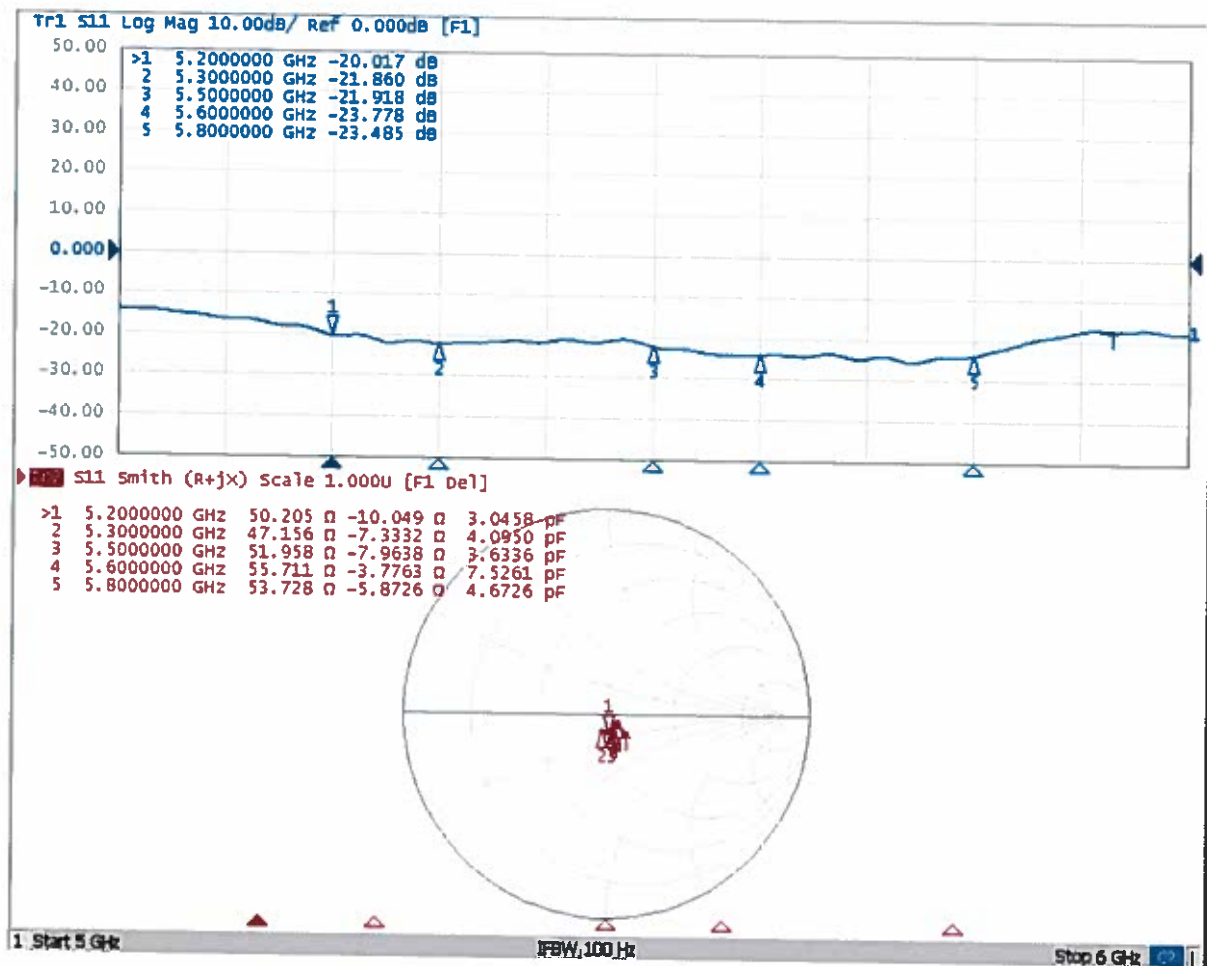




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## Impedance Measurement Plot for Head TSL



Client **SRTC (Auden)**

Certificate No: **VNA-R140-0011213\_Oct20**

## FUNCTIONAL TEST CERTIFICATE

Object **DAKS\_VNA R140 - SN: 0011213**

Test procedure(s) **QA CAL-18.v4  
Performance Check for Vector Network Analyzer and Vector  
Reflectometer**

Test date: **October 21, 2020**

The functional tests are given on the following pages and are part of the certificate.

All tests have been conducted in the closed laboratory facility: environment temperature  $(22 \pm 3)^{\circ}\text{C}$  and humidity  $< 70\%$ .

### Equipment used

| Primary Standards           | ID #                     | Cal Date (Certificate No.)        | Scheduled Calibration |
|-----------------------------|--------------------------|-----------------------------------|-----------------------|
| R&S FSV40 Spectrum Analyzer | SN: 1321.3008K40 / S4461 | 25-Feb-19 (No. 789157)            | Feb-22                |
| Type-N mismatch combination | SN: 310982 / 06327       | 31-Mar-20 (No. 217-03104)         | Apr-21                |
| Secondary Standards         | ID #                     | Check Date (in house)             | Scheduled Check       |
| Rohde & Schwarz ZVA67       | T4383                    | 16-Jan-18 (in house check Jun-20) | Jun-21                |

Tested by: **Name**  
**Claudio Leubler** **Function**  
**Laboratory Technician**

Signature



Approved by: **Katja Pokovic** **Technical Manager**



Issued: October 22, 2020

This functional test certificate shall not be reproduced except in full without written approval of the laboratory.

## References

- [1] IEEE Std 1528-2013, "IEEE Recommended Practice for Determining the Peak Spatial-Averaged Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques", June 2013
- [2] IEC 62209-1, "Measurement procedure for the assessment of Specific Absorption Rate (SAR) from hand-held and body-mounted devices used next to the ear (frequency range of 300 MHz to 6 GHz)", July 2016
- [3] IEC 62209-2, "Evaluation of Human Exposure to Radio Frequency Fields from Handheld and Body-Mounted Wireless Communication Devices in the Frequency Range of 30 MHz to 6 GHz: Human models, Instrumentation, and Procedures"; Part 2: "Procedure to determine the Specific Absorption Rate (SAR) for including accessories and multiple transmitters", March 2010
- [4] DAK Professional Handbook, SPEAG, September 2018

## Description of the Reflectometer

The Planar R140 Vector Reflectometer (Copper Mountain Technologies, Indianapolis, IN 46268, USA) is a VNA with N connector used in the DAKS [4] for measuring the complex reflection coefficient,  $S_{11}$  in the frequency range 200 MHz - 14 GHz. The device is powered and operated via USB from a PC. Reflectometer unit shall not to be disassembled from the dielectric probe when used in the DAKS system.

## Handling of the item

The R140 is a microwave measurement instrument and must be handled with care and kept clean. It shall not be inserted or come in contact with liquids.

## Methods Applied and Interpretation of Parameters

In the DAKS [4], the R140 is mounted to a dielectric probe and calibrated with it. Before using it in the DAKS configuration, performance parameters, which are not covered with the DAKS calibration, are measured in this procedure.

1. Configuration and mechanical / optical status.
2. Basic operation: Operation and setting of parameters from the PC using R140 software.
3. Ripple of  $S_{11}$  without application of calibration and with the N connector open: The variation of the reflection shows the basic functionality to measure reflection.
4. Frequency accuracy at 1 GHz and 10 GHz in comparison with a reference source: The frequency is measured in both frequency ranges (fundamental and harmonic source mode) using a spectrum analyzer and comparing it to a reference frequency source.
5. Source amplitude at high power level setting, in the frequency ranges 200 MHz - 4.8 GHz and 4.8 - 14 GHz: The available amplitude is the upper limit of the measurement dynamic range. Due to the reflectometer source characteristics, the amplitude is verified using the peak hold function of a spectrum analyzer.
6. Measurement of a 20 dB reference mismatch: After calibration with a N calibration kit HP 85032B, a calibrated N mismatch is measured and compared to the reference data in the frequency range 200 MHz - 6 GHz (used with DAKS for measurements according to standards [1], [2], [3]). The result is plotted together with the uncertainty limits of the reference mismatch calibration.

## Functional Test Results

### Configuration and mechanical / optical status

Test passed.

### Basic operation

Software version used: Planar R140, v18.3.0

Test passed.

### Ripple of $S_{11}$

Maximum  $S_{11}$  ripple in the frequency range 85 MHz – 14 GHz range, without calibration and with the N connector open: < 1 dB

### Frequency accuracy

1 GHz: deviation 0.11 kHz from reference [T0170]

10 GHz: deviation 3.59 kHz from reference [T0170]

The frequency deviation is << 100 ppm (1 MHz @ 10 GHz)

### Source amplitude

Low range:

R140 settings: 200 MHz – 4.8 GHz: IF BW 100 Hz, 16001 points, high power.

Spectrum analyzer settings: 200 MHz - 4.8 GHz, 10 MHz IFBW, 10 MHz video BW, detector: max hold.

High range:

R140 settings: 4.8 GHz – 14 GHz, IF BW 100 Hz, 16001 points, high power.

Spectrum analyzer settings: 4.8 GHz - 14 GHz, 10 MHz BW, 10 MHz video BW, detector: max hold.

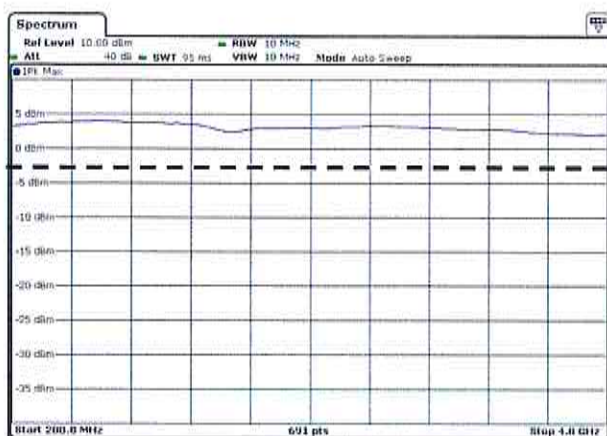


Fig. 1: Output power (low range): > -3 dBm



Fig. 2: Output power (high range): > -20 dBm

### Measurement of a 20 dB reference mismatch

After 1-port calibration performed with cal. kit [06327], the reference mismatch consisting of 10 dB reference attenuator [5047.2] and female (f) N-type short [06327] were mounted on the R140 port.

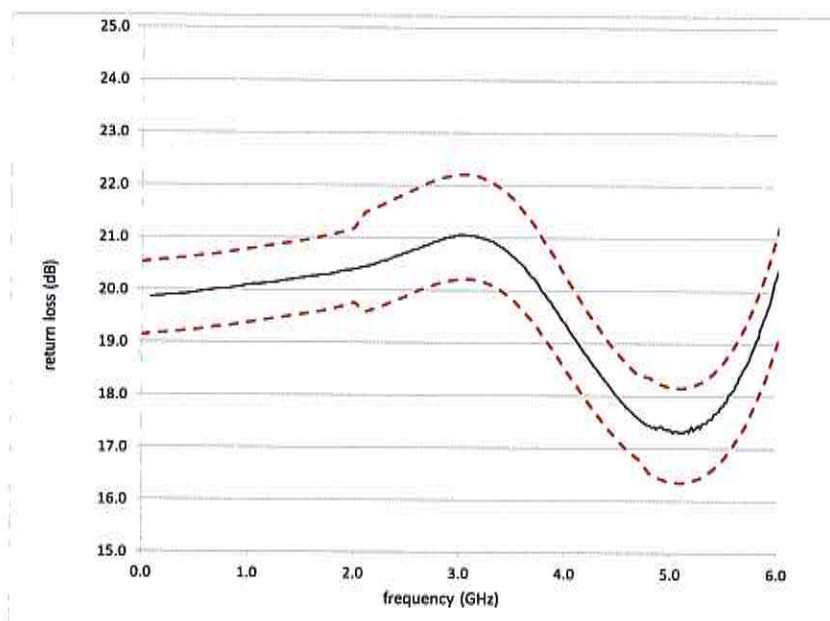


Fig. 3: Result of 20 dB mismatch with single uncertainty limit of its calibration.

The deviation of the measured 20 dB mismatch from the calibrated result is within the combined uncertainty of the 20 dB reference mismatch calibration and the Planar R140 specifications (red lines).

Note: The uncertainty has been converted from linear reflection factor to the return loss representation of Fig. 3 in dB.



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 Multilateral Agreement for the recognition of calibration certificates

Accreditation No.: **SCS 0108**

Client **SRTC (Auden)**

Certificate No: **OCP-DAKS-1042\_Oct20**

## CALIBRATION CERTIFICATE

Object **DAKS-3.5 - SN: 1042**

Calibration procedure(s) **QA CAL-33.v2**  
**Calibration of dielectric parameter probes**

Calibration date: **October 21, 2020**

This calibration certificate documents the traceability to national standards, which realize the physical units of measurements (SI).  
 The measurements and the uncertainties with confidence probability are given on the following pages and are part of the certificate.

All calibrations have been conducted in the closed laboratory facility: environment temperature ( $22 \pm 3$ )°C and humidity < 70%.

Calibration Equipment used (M&TE critical for calibration)

| Primary Standards           | ID #     | Cal Date (Certificate No.)              | Scheduled Calibration |
|-----------------------------|----------|-----------------------------------------|-----------------------|
| OCP DAK-3.5 (weighted)      | SN: 1249 | 14-Oct-20 (OCP-DAK3.5-1249_Oct20)       | Oct-21                |
| Secondary Standards         | ID #     | Check Date (in house)                   | Scheduled Check       |
| Rohde & Schwarz ZVA67       | T4383    | 16-Jan-18 (in house check Jun-20)       | Jun-21                |
| Digital Thermometer DTM3000 | 3612     | 08-May-20 (DTM-3612_May20)              | May-21                |
| Methanol 99.9% Type 34860   | STBH5818 | 06-May-19 (bottle opened, check May-20) | May-21                |
| Head Liquid, HBBL U16       | 200311-0 | 11-Mar-20 (in house check May-20)       | May-21                |
| 0.1 mol/L NaCl solution     | 190926-1 | 20-Sep-19 (in house check May-20)       | May-21                |
| 0.05 mol/L NaCl solution    | 190926-0 | 20-Sep-19 (in house check May-20)       | May-21                |
| Head Gel, SLAGH U08 AA-B    | 200227-1 | 07-Apr-20 (in house check Apr-20)       | Apr-21                |
| Eccostock0005               | 1507101  | 01-Jul-15 (in house check May-20)       | May-21                |

Calibrated by: **Name** **Function**  
**Claudio Leubler** **Laboratory Technician**

Signature

Approved by: **Katja Pokovic** **Technical Manager**

Issued: October 21, 2020

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Accreditation No.: **SCS 0108**

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## References

- [1] IEEE Std 1528-2013, "IEEE Recommended Practice for Determining the Peak Spatial-Averaged Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques", June 2013
- [2] IEC 62209-1, "Measurement procedure for the assessment of Specific Absorption Rate (SAR) from hand-held and body-mounted devices used next to the ear (frequency range of 300 MHz to 6 GHz)", July 2016
- [3] IEC 62209-2 Ed.1, "Human Exposure to Radio Frequency Fields from Handheld and Body-Mounted Wireless Communication Devices – Human models, Instrumentation, and Procedures Part 2: Procedure to determine the specific absorption rate (SAR) for mobile wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz)", March 2010
- [4] A. P. Gregory and R. N. Clarke, "NPL Report MAT 23", January 2012  
Tables of the Complex Permittivity of Dielectric Reference Liquids at Frequencies up to 5 GHz
- [5] DAK Professional Handbook, SPEAG, September 2018
- [6] A. Toropainen et al, "Method for accurate measurement of complex permittivity of tissue equivalent liquids", Electronics Letters 36 (1) 2000 pp32-34
- [7] J. Hilland, "Simple sensor system for measuring the dielectric properties of saline solutions", Meas. Sci. Technol. 8 pp901–910 (1997)
- [8] K. Nörtemann, J. Hilland and U. Kaatz, "Dielectric Properties of Aqueous NaCl Solutions at Microwave Frequencies", J. Phys. Chem. A 101 pp6864-6869 (1997)
- [9] R. Buchner, G. T. Heffer and Peter M. May, "Dielectric Relaxation of Aqueous NaCl Solutions", J. Phys. Chem. A 103 (1) (1999)

## Description of the dielectric probe

Dielectric probes are used to measure the dielectric parameters of tissue simulating media in a wide frequency range. The complex permittivity  $\epsilon_r^* = (\epsilon'/\epsilon_0) - j(\epsilon''/\epsilon_0)$  is determined from the S parameters measured with a vector network analyzer (VNA) with software specific to the probe type. The parameters of interest e.g. in standards [1, 2, 3] and for other applications are presented are calculated as follows:

(Relative) permittivity  $\epsilon'$  (real part of  $\epsilon_r^* = (\epsilon'/\epsilon_0) - j(\epsilon''/\epsilon_0)$  where  $\epsilon_0 = 8.854 \text{ pF/m}$  is the permittivity in free space)

Conductivity  $\sigma = 2 \pi f \epsilon'' \epsilon_0$ ,

Loss Tangent =  $(\epsilon''/\epsilon')$

The **OCP** (open ended coaxial) is a cut off section of 50 Ohm transmission line, similar to the system described in [1, 2, 3, 5], used for contact measurement. The material is measured either by touching the probe to the surface of a solid/gelly or by immersing it into a liquid media. The electromagnetic fields at the probe end fringe into the material to be measured, and its parameters are determined from the change of the  $S_{11}$  parameters. With larger diameter of the dielectrics, the probe can be used down to lower frequencies.

The flange surrounding the active area shapes the near field similar to a semi-infinite geometry and is inserted fully into the measured lossy liquid.

The probe is connected with a phase and amplitude stable cable to a VNA which is then calibrated with Open, Short and a Liquid with well-known parameters.  
All parts in the setup influencing the amplitude and phase of the signal are important and shall remain stable.

### Handling of the item

Before usage, the active probe area has to be cleaned from any material residuals potentially contaminating the reference standards. The metal and dielectric surface must be protected to keep the precision of the critical mechanical dimensions. The connector and cable quality are critical; any movements between calibration and measurement shall be avoided.  
The temperature must be stable and must not differ from the material temperature.

### Methods Applied and Interpretation of Parameters

The calibration of the dielectric probe system is done in the steps described below for the desired frequency range and calibration package (SAR/MRI liquids, Semi-solid/solid material). Because the standard calibration in step 3 is critical for the results in steps 4 to 8, the sequence 3 to 8 is repeated 3 times. As a result, the result from these 3 sets is represented.

1. Configuration and mechanical / optical status.
2. Measurement resolution is 5 MHz from 10 to 300 MHz, 50 MHz from 300 to 6000 MHz and 250 MHz from 6 to 20 GHz.
3. Standard calibration uses Air / Short / Liquid. 1 liter liquid quantity is used to reduce the influence the reflections. The liquid type is selected depending on the lowest frequency and probe diameter:  
DAK-1.2, DAK-3.5, Agilent OCP: de-ionized water (approx. 22 °C)  
DAK-12: saline solution with static conductivity 1 S/m (approx. 22 °C)  
NPL OCP: pure ethanol (approx. 22 °C)
4. The cable used in the setup stays in a fixed position, i.e. the probe is fixed and measuring from the top in an angle of typ. 20° from the vertical axis. For DAK and Agilent probes, the refresh function (air standard) is used previous to the individual measurements in order to compensate for possible deviations from cable movements. After insertion of the probe into a liquid, the possible air bubbles are removed from the active surface.
5. Measurement of multiple shorts if not already available from the calibration in the previous step (NPL). Evaluation of the deviation from the previous calibration short with graphical representation of the complex quantities and magnitude over the frequency range. Probe specific short is used. This assessment shows ability to define a short circuit at the end of the probe for the VNA calibration in the setup which is essential at high frequencies and depends on the probe surface quality.
6. Measurement of validation liquids in a quantity of 1 liter at well defined temperature. Evaluation of the deviations from the target. The targets base on traceable data from reference sources. The deviation of the measurement is graphically presented for permittivity and conductivity (for lossy liquids) or loss tangent (for low losses at low frequencies).
7. Measurement of lossy liquids in a quantity of 1 liter at well defined temperature. Head tissue simulating liquid or saline solution with 0.5 S/m static conductivity are representative. The target data base on traceable data from reference sources or from multiple measurements with precision reference probes or different evaluations such as transmission line or slotted line methods. Evaluation of the deviation from the target and graphical representation for permittivity and conductivity over the frequency range
8. Semi-solid / solid material calibration:  
Measurements of an elastic lossy broadband semi-solid gel with parameters close to the head tissue target. Measurements of a planar very low loss solid microwave-substrate. The average of 4 measurements of the same sample at different location is shown as a single result. The deviation of the permittivity and conductivity from the reference data is evaluated.  
Measurements of a planar very low loss solid microwave-substrate. The average of 4 measurements of the same sample at different location is shown as a single result. The relative deviation of the permittivity and the absolute deviation of the loss tangent is evaluated.  
The targets base on multiple measurements (on the same material batch at identical temperature) on convex and planar surfaces with precision reference OCP.

The measurement on semi-solid / solid materials is sensitive to the quality and planarity of the probe contact area, such as air gaps due to imperfect probes (resulting lower permittivity values).

9. Table for the probe uncertainty: The uncertainty of the probe depending on probe type, size, material parameter range and frequency is given in a table. It represents the best measurement capability of the specific probe but does not include the material (deviation from the target values).
10. Appendix with detailed results of all measurements with the uncertainties for the specific measurement. In addition to the probe uncertainty (see above), it includes the uncertainty of the reference material used for the measurement. A set of results from independent calibrations represents the capability of the setup and the lossy materials used, including the precision of the measured material and the influence of temperature deviations. Temperature and operator influence was minimized and gives a good indication of the achievable repeatability of a measurement.
11. Summary assessment of the measured deviations and detailed comments if not typical for the probe type.

#### Dielectric probe identification and configuration data

##### Item description

|                  |                                                                                                                                                         |
|------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| Probe type       | <b>OCP</b> Open-ended coaxial probe                                                                                                                     |
| Probe name       | SPEAG Dielectric Assessment Kit DAK-3.5                                                                                                                 |
| Type No          | <b>SM DAK 500 AA</b>                                                                                                                                    |
| Serial No        | <b>1042</b>                                                                                                                                             |
| Description      | Open-ended coaxial probe with flange<br>Flange diameter: 19.0 mm<br>Dielectric diameter: 3.5 mm<br>Material: stainless steel                            |
| Connector 1      | N pos.                                                                                                                                                  |
| Software version | <b>DAK Measurement Solver 2.6.1.7</b><br>Calibration Type: Air / short / water (set to measured water temp.)<br>Probe type: "DAK3.5" (software setting) |
| Further settings | VNA bandwidth setting: 50 Hz                                                                                                                            |

##### SCS 0108 Accessories used for customer probe calibration

|       |                                                                                           |
|-------|-------------------------------------------------------------------------------------------|
| Cable | Huber & Suhner Sucoflex 404, SN: 4361, length 1 m,<br>PC3.5 neg. – PC3.5 neg.             |
| Short | DAK-3.5 shorting block, type SM DAK 200 BA<br>Contact area covered with cleaned Cu stripe |

##### Additional items used during measurements

|           |                                                           |
|-----------|-----------------------------------------------------------|
| Adapter 1 | PC3.5 pos. – PC2.4 (VNA side)                             |
| Adapter 2 | PC3.5 pos. – PC3.5 neg. (probe side)                      |
| Adapter 3 | N neg. – PC3.5 neg. (probe side, between probe and cable) |

#### Notes

- Before the calibration, the connectors of the probe and cable were inspected and cleaned.
- Probe visual inspection: according to requirements
- Short inspection: according to the requirements

## Probe Uncertainty

The following tables provide material and frequency specific uncertainties (k=2) for the dielectric probe. The values in the tables represent the measurement capability for the probe when measuring a material in the indicated parameter range. They include all uncertainties of

- probe system
- possible systematic errors due to the design
- calibration
- temperature differences during the calibration and measurements, as described,
- VNA noise

Apart from the material used for the calibration (de-ionized water), material uncertainties of the reference materials used during the measurement in Appendix A are not included in these tables.

| <b>DAK-3.5</b>           |          |                 |                      |            |
|--------------------------|----------|-----------------|----------------------|------------|
| Permittivity range       |          | Frequency range | (sigma / LT range)   | Unc. (k=2) |
|                          | 1 – 15   | 200 MHz - 3 GHz | LT < 0.1             | 2.4%       |
|                          |          | 3 GHz - 6 GHz   | LT < 0.1             | 2.0%       |
|                          |          | 6 GHz - 20 GHz  | LT < 0.1             | 2.1%       |
|                          |          | 6 GHz - 20 GHz  | sigma > 1            | 3.5%       |
|                          |          |                 |                      |            |
|                          | 10 – 40  | 200 MHz - 3 GHz | sigma : 1 – 10 S/m   | 1.9%       |
|                          |          | 3 GHz - 6 GHz   | sigma : 1 – 10 S/m   | 2.3%       |
|                          |          | 6 GHz - 20 GHz  | sigma > 10 S/m       | 3.5%       |
|                          |          |                 |                      |            |
|                          | 35 – 100 | 200 MHz - 3 GHz | sigma : 1 – 10 S/m   | 1.7%       |
|                          |          | 3 GHz - 6 GHz   | sigma : 1 – 10 S/m   | 1.9%       |
|                          |          | 6 GHz - 20 GHz  | sigma > 10 S/m       | 2.4%       |
|                          |          |                 |                      |            |
| Conductivity range (S/m) |          | Frequency range | (epsilon / LT range) | Unc. (k=2) |
|                          | 1 – 10   | 200 MHz - 3 GHz | eps : 35 - 100       | 2.7%       |
|                          |          | 3 GHz - 6 GHz   | eps : 35 - 100       | 3.0%       |
|                          |          | 6 GHz - 20 GHz  | eps : 10 - 40        | 3.0%       |
|                          |          |                 |                      |            |
| Loss tangent range       |          | Frequency range | (epsilon / LT range) | Unc. (k=2) |
|                          | < 0.1    | 200 MHz - 3 GHz | eps : 1 - 15         | 0.03       |
|                          |          | 3 GHz - 6 GHz   | eps : 1 - 15         | 0.03       |
|                          |          | 6 GHz - 20 GHz  | eps : 1 - 15         | 0.03       |

## Calibration Results

Uncertainty limits ( $k=2$ ) for the material measurements in the figures of Appendix A are represented with red dashed lines. These uncertainties contain - in addition to probe uncertainty - the uncertainty of the material target parameter determination.

The measurements show the results obtained from independent calibrations for the same material. The differences between the individual measurement curves give therefore an indication for the obtainable repeatability and shall lie within the uncertainties stated in the tables.

*Materials for DAK-3.5 calibration:*

*Appendix A with curves for Methanol, HSL, and 0.05 mol/L NaCl solution (200 MHz - 6 GHz, optional 14 GHz), HS gel and low loss solid substrate are optional.*

## Appendix A: Detailed Results

### A.1 Probe appearance and calibration sequence

#### A.1.1 Appearance

The OCP appearance is fully according to the expectations:

- the flange surface is intact

#### A.1.2 Calibration sequence

The following sequence was repeated 3 times in the low frequency range from 200 – 300 MHz in 5 MHz steps and in the high frequency range from 300 to 6000 MHz in 50 MHz steps, and from 6 GHz to 14 GHz in 250 MHz steps.

- Air
- Short 1 short, then immediate verification with a second short (with eventual repetition)
- Water De-ionized water, temperature measured and set in the software (for DAK-12 0.1 mol/L saline solution, temperature measured and set in the software)
- Methanol Pure methanol, temperature measured and set in the software
- Liquids Measurement of further liquids (e.g. Head tissue simulating liquid and 0.05 mol/l saline)
- Cleaning Probe washed with water and isopropanol at the end of the sequence.
- Shorts 4 additional separate short measurements to determine the deviation from the original
- Refresh Refresh with Air
- Solid 4 separate solid low loss planar substrate measurements to determine one average (optional)
- Semisolid 4 separate head gel measurements on fresh intact surface to determine one average (optional)
- Cleaning Probe washed with water and isopropanol at the end of the sequence

Evaluation of the additional shorts from the calibrated (ideal) short point at the left edge of the Smith Chart, represented as magnitude over the frequency range (fig. 2.1.x) and in polar representation (fig. 2.2.x).

Evaluation of the Liquid measurements and representation of the permittivity and conductivity deviation from their reference data at the measurement temperature. The results of each of the 3 calibrations is shown in the appendix for each material (fig. 3ff) in black, red, blue. The red dashed line shows the uncertainty of the reference material parameter determination.

Evaluation of the Semisolid measurements (optional) by representing the 3 average deviations (each resulting from the 4 separate measurements per set), equivalent to the liquid measurement. Representation of the permittivity and conductivity deviation from their reference data at the nominal temperature.

Evaluation of the Solid measurements (optional) by representing the 3 average deviations (each resulting from the 4 separate measurements per set), equivalent to the liquid measurement. Representation of the permittivity deviation from their reference data and the loss tangent at the nominal temperature.

## A.2 Short residual magnitudes

After each of the 3 calibrations with a single short (as per the DAK software), 4 additional separate, short measurements were performed after the liquid measurements and evaluated from the S11 data. The residuals in the graphs represent the deviation from the ideal short point on the polar representation on the VNA screen.

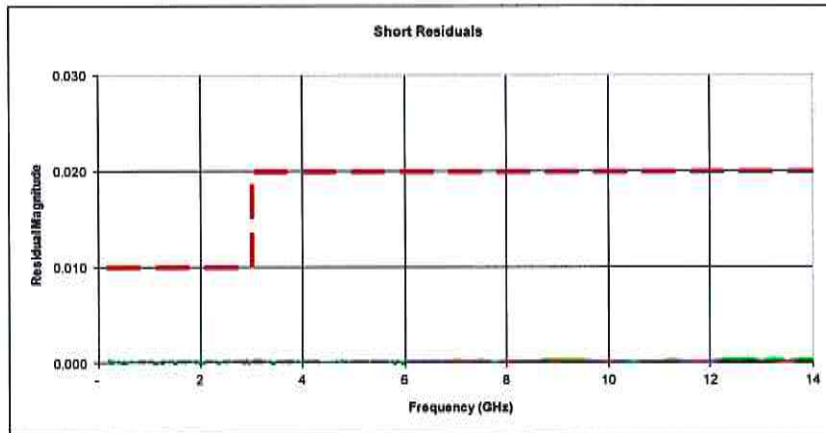


Fig. 2.1a Magnitude of the residual of the shorts, 200 MHz – 14 GHz, after calibration a)

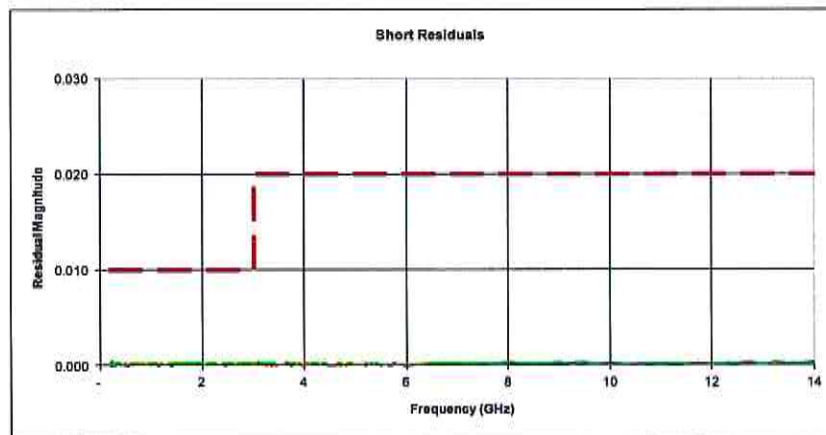


Fig. 2.1b Magnitude of the residual of the shorts, 200 MHz – 14 GHz, after calibration b)

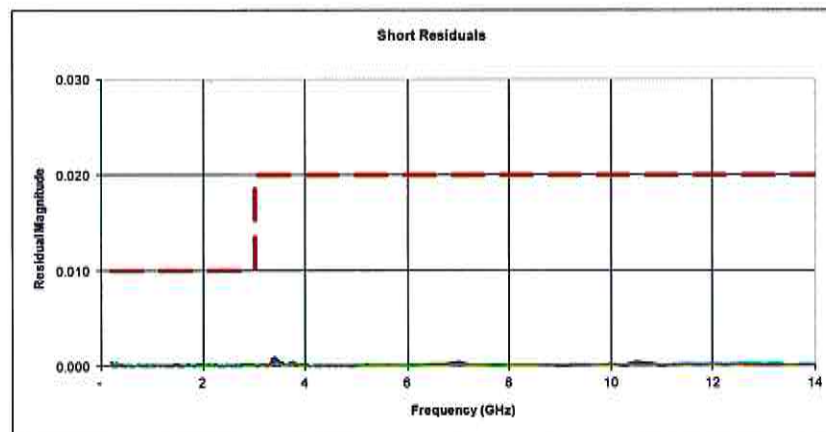


Fig. 2.1c Magnitude of the residual of the shorts, 200 MHz – 14 GHz, after calibration c)

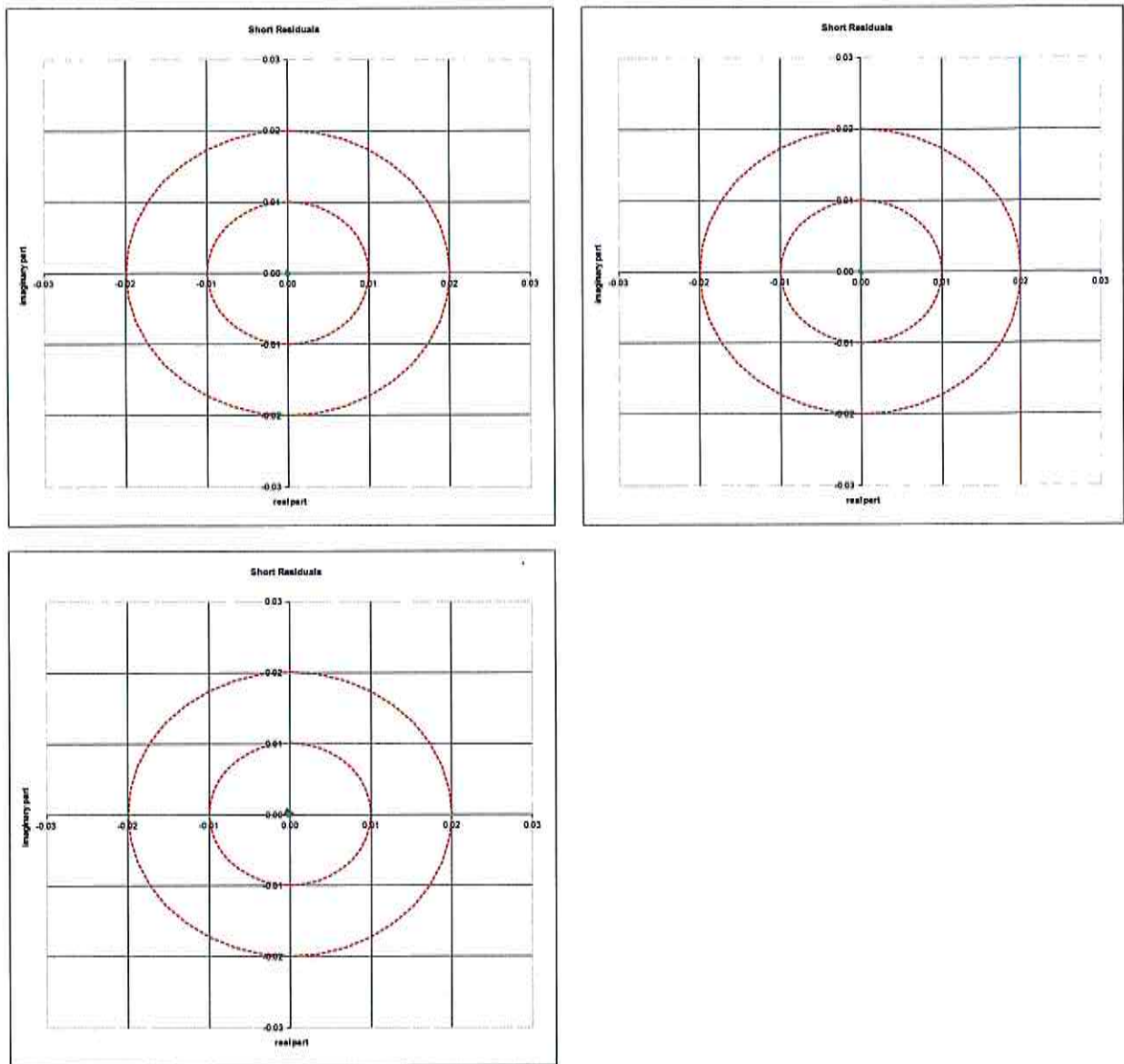


Fig. 2.2a-c Complex representation of the residuals of the shorts, 200 MHz - 14 GHz, after calibrations a)-b) in the top and c) in the bottom

All shorts have good quality. Some minor deviations might be visible from contact quality (left - right).

### A.3 Methanol

Methanol (99.9% pure) was measured at a temperature of  $22 \pm 2$  °C. The liquid temperature was stabilized within 0.05 °C of the desired temperature. Deviations are presented relative to the nominal material parameters at this temperature, calculated from NPL data for this temperature. For the measurements the Noise Filter was activated in the software.

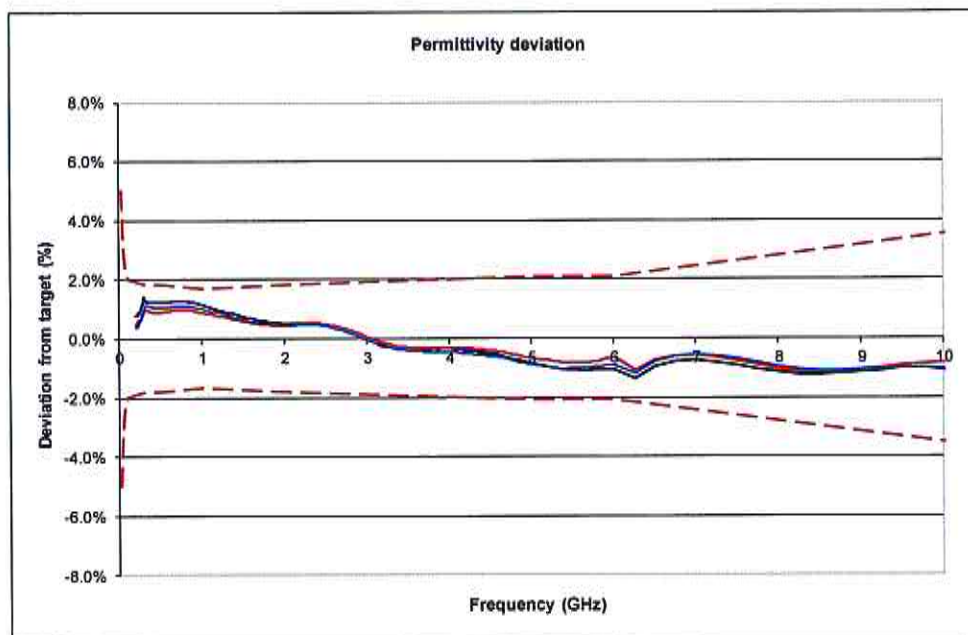


Fig. 3.1 Methanol permittivity deviation from target, 200 MHz – 10 GHz

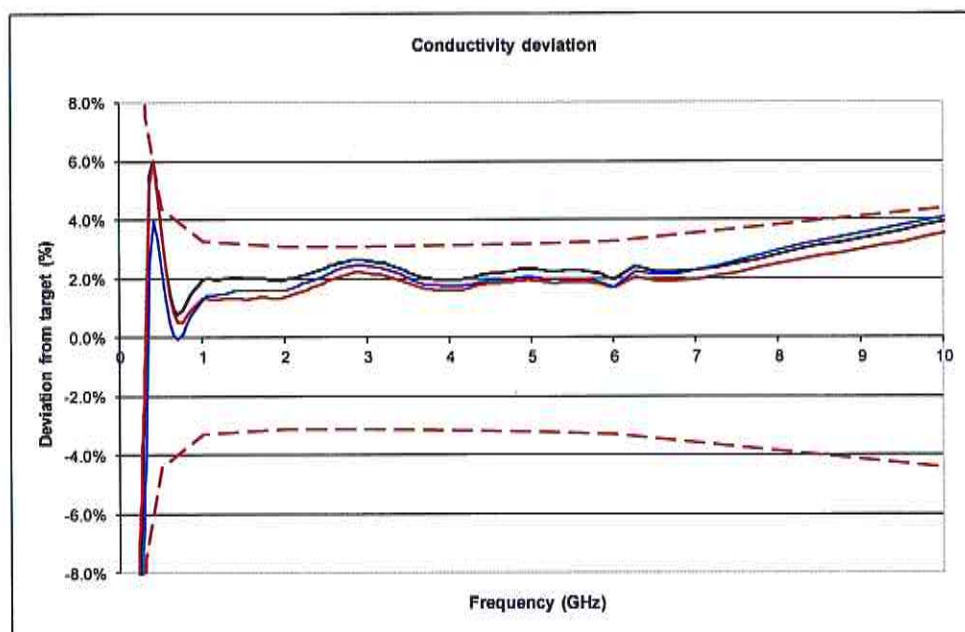


Fig. 3.2 Methanol conductivity deviation from target, 200 MHz – 10 GHz

**Note:** Conductivity error can be high at low frequencies due to the low absolute conductivity values.